Environmental Studies No.58

The Potential Effects of Tanker Traffic on the Bowhead Whale in the Beaufort Sea

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Northern Affairs Program

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EXECUTIVE SUMMARY

Offshore exploration for oil and gas under waters used by the endangered bowhead whale began in 1976 in the Canadian Beaufort Sea. The largest oil find to date is the Amauligak structure about 50 km north of the Mackenzie River delta. Original plans called for initial production beginning in the late summer of 1988 with a shuttle tanker being used to transport crude oil from Amauligak to a large oil tanker stationed off the northwest coast of Alaska. The shift from exploration to production raises concerns about the potential effects of the increased ship traffic on the bowheads that summer in, and migrate through, the Beaufort Sea.

Since 1980 major studies of the potential effects of industrial activity on bowheads have been funded by the U.S. government (Minerals Management Service), Canadian government (Department of Indian Affairs and Northern Development), and the oil industries of both countries. In addition major studies of bowhead reproductive biology and censuses of population size have been undertaken to evaluate and support the subsistence harvest of bowheads by Alaskan Inupiat whalers. The accumulated data from the various studies have not been integrated to examine questions beyond the original purposes of the studies. The study reported here performed such an integration to examine a series of questions related to the assessment of possible effects of the proposed initial production and transportation from Amauligak.

Several of the topics addressed in this report relate to questions and concerns first identified by a workshop conducted by the Beaufort Environmental Monitoring Project (BEMP) sponsored by DIAND and DOE in Victoria, B.C. in March 1987. The principal findings regarding these questions and other factors that affect the design of monitoring projects are summarized below.

Distribution of Calves

Based on data from 1986, the BEMP workshop expressed concern that the proposed tanker traffic from Amauligak would traverse an important calf-rearing area. Review of all available data showed that a tanker route extending west from Amauligak would have influenced large numbers of calves in

summer in only one (1982) of the seven years with data. Cows and calves migrate through the Alaskan Beaufort Sea primarily in late September, but are fairly widely spread through nearshore and offshore waters at that time and concentrations are uncommon.

Age Segregation

There was some evidence that age segregation occurred on the summering grounds. It is important to evaluate this segregation to determine if particular segments of the population are more or less likely to be exposed to tanker traffic. A detailed analysis of length frequency data derived from aerial photogrammetry was performed in this study. Age segregation was found to be very pronounced with some regular patterns, but much variability. The waters west of Amauligak are occupied in August and September of most years by the 'small and medium subadult' component of the population. In some years (1985 for example), virtually the entire subadult component of the population would be exposed to ship noise from the proposed tanker traffic. In most years, few summering adults would be exposed to noise since they occur farther east and farther offshore. However, adults would be affected in some years (e.g., 1982) and during fall migration off the Yukon and Alaska coasts.

Age segregation patterns were found to be very complex and the reader is referred to that section of the report for details.

Effects of Age on Bowhead Behavior

Any analysis of whale behavior in response to ship traffic must be able to relate the observed behavior to known patterns of normal behavior in undisturbed situations. Because of the pronounced age segregation found on the summering grounds, it was important to determine whether the various age classes have different patterns of normal behavior and/or responses to disturbance. Sample sizes were not sufficient to fully answer this point, but it is clear that the behavior of bowheads in deep water was statistically different than in shallow water and older, larger whales tended to occur in the deeper water. Thus, any study of the effects of tanker traffic on whale behavior must account for water depth and, probably, whale size (= age).

Photo Identification File and Data Base

One of the beneficial results of this study has been the establishment in Canada of a complete inventory of all re-identifiable bowhead photographs from the western Arctic summering grounds. Also the file is now accompanied by a computerized data base that contains all relevant information about the photographs, whale lengths and re-identifications.

Micro-scale Movements

Analysis of the locations of whales rephotographed on the same day indicated that even undisturbed whales averaged net rates of movement of about 2 km/h. Thus, even in the absence of a disturbance source, such as a tanker, individual whales are expected to move several km in an hour or two. There is a danger of improperly classifying such movements as responses to tankers rather than as natural movements. The design of 'tanker effect' studies must allow for these patterns of local movement.

Site Fidelity Within a Season

Analysis of whales resighted on more than one day within a year indicated that whales tended to remain within a particular zone while on the summering grounds. Overall, net rates of movement averaged 5.9 km/day for the 96 pairs of between-day resightings. Thus, whales that summer in areas traversed by the tanker route are likely to be exposed to ship noise on several occasions during the summer. Other animals to the north and east would remain free of disturbance except when they undertake fall migration. There was little evidence that individual whales associated with each other for extended periods (e.g., several days). Thus, dissolution of groups of whales exposed to ship traffic would be expected even in the absence of the ship.

Between-Year Site Fidelity

There was some evidence that the adult whales that fed in the Franklin Bay area tended to occur there in subsequent years. Thus, this component of the population would not be exposed to ship traffic. The subadult component that summers along the Yukon coast and the edge of the Mackenzie plume would

be subject to repeated disturbances over a number of years since individuals tend to return to this region in subsequent years.

Known Effects of Ship Traffic

The data on responses of bowheads to ships were reviewed and quantified where possible. Bowheads clearly respond to approaching ships with overt responses beginning at distances of 1 to 7 km. Bowheads seem to move up to 6 km to the side of the track of a passing ship with reactions diminishing soon after the ship starts to move away. These evasive movements are conducted at 3-10 km/h and take ½ to 2 hours. It was found earlier in this study that whales moved at an average of 2 km/h in the absence of disturbance. Thus, an individual would normally move 6 km in about 3 h. The similarity of the distances moved to avoid ships and distances normally moved, mean that extreme care is needed when studying and interpreting short-term responses of bowheads to ship traffic.

Separation of Cow-Calf Pairs

The BEMP workshop identified the possibility that cow-calf pairs might become permanently separated if tanker noise prevented communication between the cow and the calf. The available data on whale response criteria, whale calls, ship noise, transmission loss, and ambient noise were modelled to assess the likelihood of cow-calf separation. The results indicate that permanent separation is very unlikely.

Interference with Bowhead Movements

Concern has been expressed at BEMP, and by other sources, that tanker traffic might cause whale displacement that would interfere with the coastal harvest in Alaska in fall. The available information on hunting areas, whale distribution, and reactions to ships was assessed. On most passages, the tanker will not affect the huntable nearshore whales. In some cases when ice forces the ship to pass within 20-40 km of shore, some whales may move away from the ship into nearshore hunting areas thereby increasing hunting success. On rare occasions the tanker might travel closer than 20 km from shore. In

these cases, negative effects on the hunt might occur, but is not possible to determine a single specific distance at which detrimental effects might begin.

It is likely to be extremely difficult to effectively monitor this situation to determine whether the hunt is affected by the tanker traffic. Direct observation from aircraft is the most practical method, but this is not likely to be permitted in areas where the hunt is occurring.

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RÉSUMÉ À L'INTENTION DE LA DIRECTION

L'exploration pétrolière et gazière en mer dans les eaux fréquentées par la baleine boréale, menacée d'extinction, a commencé en 1976 dans la mer de Beaufort canadienne. La plus grande découverte de pétrole faite à ce jour est la structure Amauligak, située à environ 50 km au nord du delta du Mackenzie. À l'origine, on prévoyait commencer la production à la fin de l'été de 1988; un pétrolier navette devait servir à transporter le pétrole brut du gisement d'Amauligak jusqu'à un grand pétrolier mouillé au large de la côte nord-ouest de l'Alaska. Le passage de l'exploration à la production suscite de nombreuses inquiétudes quant aux effets possibles de l'augmentation du trafic maritime sur les baleines boréales qui estivent dans la mer de Beaufort, ou qui la traversent dans leur migration.

Depuis 1980, les grandes études sur les effets possibles de l'activité industrielle sur les baleines boréales ont été financées par le gouvernement des États-Unis (Minerals Management Service), par le gouvernement du Canada (ministère des Affaires indiennes et du Nord) ainsi que par les industries pétrolières des deux pays. D'autres grandes études portant sur la biologie de la reproduction de la baleine boréale ainsi que sur la taille de la population ont été entreprises afin d'évaluer et d'appuyer les activitiés de chasse de subsistance des baleiniers inupiat de l'Alaska. Les données collectées grâce à ces diverses études n'ont pas été unifiées, et n'ont servi à ce jour qu'à l'examen des questions définies à l'origine dans les études particulières. Les auteurs de la présente étude ont réalisé une telle unification, afin de chercher à évaluer les effets possibles des activités projetées de production initiale et de transport pour le gisement d'Amauligak.

Plusieurs des sujets dont il est question dans la présente étude découlent de préoccupations exprimées une première fois par les participants à un atelier organisé par le Projet de surveillance de l'environnement dans la mer de Beaufort (PSEMB) et parrainé par le MAIN et par Environment Canada. Cet atelier a eu lieu à Victoria, en Colombie-Britannique, en mars 1987.

Les constatations principales relatives à ces sujets ainsi qu'à d'autres facteurs qui influent sur la conception des projets de contrôle sont résumées ci-dessous.

Distribution des baleineaux

Se fondant sur des données de 1986, les participants à l'atelier du PSEMB se sont dits inquiets du fait que le trafic projeté des pétroliers en provenance du gisement d'Amauligak traverserait une importance zone d'élevage de baleineaux. Un examen de toutes les données existantes a montré que l'établissement d'une voie pour pétroliers allant vers l'ouest à partir du gisement d'Amauligak n'aurait perturbé un grand nombre de baleineaux l'été qu'au cours d'une seule (1982) des sept années pour lesquelles il existait des données. Les femelles et les baleineaux traversent la mer de Beaufort de l'Alaska dans leur migration essentiellement vers la fin septembre, mais ils sont assez largement distribués entre les eaux du littoral et de la haute mer à ce moment-là et il est rare qu'on les trouve en grande concentration.

Ségrégation par âge

Des données indiquent qu'il y a ségration par âge chez les baleines fréquentant les eaux d'estivage. Il est important d'évaluer cette ségrégation afin de déterminer si des couches particulières de la population seront plus ou moins vraisemblablement exposées au trafic des pétroliers. Les auteurs de la présente étude ont réalisé une analyse détaillée de données sur la fréquence des longueurs de baleine obtenues par photogrammétrie aérienne. Il a été constaté qu'il existait une forte ségrégation par âge présentant quelques tendances régulières, mais aussi une très grande variabilité. Les eaux à l'ouest du gisement d'Amauligak sont fréquentées pendant les mois d'août et septembre la plupart des années par la couche "subadulte petit et moyen" de la population. Certaines années (1985 par exemple), presque toute la couche subadulte de la population serait exposée au bruit produit par le trafic projeté des

pétroliers. Dans la plupart des années, peu d'adultes en estivage seraient exposés à ce bruit, car ils fréquentent des eaux éloignées à l'est et au large. Cependant, les adultes seraient également perturbés certaines années par ce bruit (par exemple 1982) ainsi que pendant la migration d'automne, lorsqu'ils quittent les côtes du Yukon et de l'Alaska.

La structure de la ségrégation par âge est extrêmement complexe et le lecteur est prié de se reporter à la section qui traite du sujet pour obtenir de plus amples renseignements.

Effets de l'âge sur le comportement de la baleine boréale

Toute analyse du comportement de la baleine boréale en réponse au trafic maritime doit permettre de comparer le comportement observé au comportement normal connu sans perturbation. En raison de la forte ségrégation par âge constatée dans les eaux d'estivage, il importe de déterminer si les diverses classes d'âge ont des comportements normaux différents, ou encore si les comportements observés sont l'effet de perturbations. La taille des échantillons n'a pas été suffisante pour permettre de répondre entièrement à cette question, mais il est manifeste que le comportement des baleines boréales en eau profonde était statistiquement différent de leur comportement en eau peu profonde, et que les grandes baleines âgées avaient tendance à fréquenter les eaux plus profondes. Ainsi, toute étude des effets du trafic pétrolier sur le comportement des baleines doit prendre en compte la profondeur des eaux ainsi que, probablement, la taille (âge) des baleines.

Fichier et base de données de photo-identification

Un des résultats positifs de la présente étude a été l'établissement au Canada d'un répertoire complet de toutes les photographies des baleines identifiables prises dans les eaux d'estivage de l'Arctique occidental. Le fichier s'accompagne maintenant d'une base de données informatisée qui contient tous les renseignements pertinents sur ces photographies, la longueur des baleines et les identifications répétées.

Déplacements à petite échelle

Une analyse de l'emplacement des baleines rephotographiées le même jour indique que les baleines se déplacent à la vitesse résultante moyenne d'environ 2 km/h, même lorsqu'elles ne sont pas perturbées. Ainsi, en l'absence d'une source de perturbations, tel un pétrolier, les baleines devraient se déplacer de plusieurs kilomètres en l'esplace d'une heure ou deux. On risque donc d'interpréter de tels déplacements comme étant une réaction à la présence des pétroliers. Toute étude portant sur l'effet des pétroliers doit prendre en compte ces déplacements naturels à petite échelle.

Fréquentation des mêmes sites au cours d'une même saison

Une analyse des données sur les baleines vues plus d'une journée pendant la même année indique que les baleines ont tendance à demeurer dans une région particulière des eaux d'estivage. Dans l'ensemble, les vitesses résultantes de déplacement ont été en moyenne de 5,9 km/jour pour les 96 paires d'observations sur plus d'un jour. Ainsi donc, les baleines qui estivent dans les régions traversées par la voie des pétroliers seront vraisemblablement exposées au bruit de ces pétroliers à plusieurs reprises au cours de l'été. Les autres baleines des eaux situées au nord et à l'est ne seront pas perturbées, sauf au moment où elles entreprendront leur migration d'automne. Peu de données indiquent que des baleines s'associent pendant des périodes prolongées (plusieurs jours). La débandade de groupes de baleines exposées au trafic des pétroliers se ferait donc vraisemblablement même en l'absence de pétroliers.

Fréquentation des mêmes sites d'une année à l'autre

Des données indiquent que les baleines adultes qui se sont alimentées dans la région de la baie Franklin ont tendance à fréquenter ces eaux dans les années subséquentes. Cette couche de la population ne serait donc pas exposée au trafic maritime. La couche subadulte qui estive le long de la

côte du Yukon et sur la bordure du panache du Mackenzie serait perturbée de façon répétée sur un certain nombre d'années, puisque les baleines qui la composent tendent à revenir dans cette région les années subséquentes.

Effets connus du trafic maritime

Les données sur la réaction des baleines boréeales au trafic maritime ont été revues et quantifiées lorsque cela était possible. Les baleines boréales réagissent manifestement à l'approche d'un navire, la réponse devenant franche à des distances variant de 1 à 7 km. Les baleines semblent s'éloigner latéralement de jusqu'à 6 km du corridor de passage d'un navire, la réaction diminuant rapidement après le passage du navire.

Ces mouvements d'évasion se font à une vitesse se situant entre 3 et 10 km/h et prennent de 1/2 heure à 2 heures. Il a été constaté antérieurement dans la présente étude que les baleines se déplacent à une vitesse moyenne de 2 km/h en l'absence de perturbations. Autrement dit, une baleine se déplacerait normalement de 6 km dans 3 heures environ. Il existe donc une grande ressemblance entre les déplacements d'évasion et les déplacements normaux, ce qui signifie qu'il faudra exercer une attention extrême dans l'étude et l'interprétation des réactions à court terme des baleines au trafic maritime.

Séparation des paires baleineau-femelle

Les participants à l'atelier du PSEMB ont souligné qu'il était possible que la séparation de paires baleineau-femelle puisse être permanente si le bruit des pétroliers empêchait la communication entre le baleineau et la femelle. Les données existantes sur les critères de réponse des baleines, sur les appels des baleines, le bruit des navires, la perte de transmission et le bruit ambiant ont été modélisées afin d'évaluer la probabilité qu'il y ait séparation d'un baleineau et d'une femelle. Les résultats indiquent que les séparations permanentes sont très peu probables.

Interférence avec les déplacements des baleines

Les participants à l'atelier du PSEMB, ainsi que d'autres personnes, ont dit s'inquiéter que le trafic des pétroliers puisse interférer avec les déplacements des baleines d'une manière qui génerait les pêches côtières d'automne sur la cote de l'Alaska. Les renseignements existants sur les zones de chasse, la distribution des baleines et leurs réactions au passage de navires ont été évalués. Sur la majeure partie de leurs voies de passage, les pétroliers ne perturberont pas les déplacements des baleines chassables fréquentant les eaux littorales. Dans certains cas, lorsque la présence de glaces forcerait les navires à passer à moins de 20-40 km du littoral, certaines baleines pourraient s'éloigner du navire et, ce faisant, se rapprocher des zones de chasse du littoral, ce qui aurait pour effet d'accroitre le succès de la chasse. À de rares occasions, les pétroliers pourraient passer à moins de 20 km de la côte. Dans ce case, ils pourraient avoir des effets négatifs sur la chasse, mais il n'est pas possible de déterminer la distance précise à laquelle de tels effets nuisibles commencent.

Il est vraisemblable qu'il sera extrêmement difficile de contrôler efficacement la situation afin de déterminer si les résultats de la chasse dépendent du trafic maritime. L'observation aérienne directe est la méthode la plus commode, mais il est peu vraisemblable qu'on la permette pendant la chasse.

INTRODUCTION

Offshore exploration for oil and gas in waters deep enough to be used by bowhead whales began in 1976 in the Canadian Beaufort Sea and in the 1980's in the Alaskan Beaufort Sea. The largest find to date has been the Amauligak structure about 50 km north of the Mackenzie Delta (Fig. 1). Gulf Canada Resources Inc. and partners originally planned to begin production of crude oil from Amauligak in 1988. Initial plans called for oil to be produced from the Amauligak structure and loaded onto an ice-strengthened shuttle tanker for trans-shipment to a supertanker anchored in ice-free waters off Alaska--probably in the Chukchi Sea. The route followed by the shuttle tanker would be variable depending on the location of the supertanker and ice conditions between it and Amauligak. In Canadian waters, the route would be less variable because of the fixed position of the production platform. In addition to the specific route, the zone of potential influence around the shipping corridor could be substantial because of the underwater noise generated by this type of ship (cf. MV Arctic, Finley et al. 1983, 1984). Thus, a relatively wide corridor would be subject to repeated ship traffic and associated noise intermittently throughout the summer and fall periods.

It is during this summer and fall open-water period that the endangered bowhead whale occupies its summering grounds in the Beaufort Sea. Also the fall bowhead migration proceeds westward off the north coast of Alaska over the same route that would be used by tankers from Amauligak. Thus, during both summer and fall, bowhead whales would be exposed to tanker traffic. It is important to determine whether this traffic will have any detrimental effect on the whale population.

When the Environmental Assessment Review Panel (EARP) held its formal review of hydrocarbon production in the Canadian Beaufort Sea, it recommended that a phased approach to development be used and that each incremental phase of development be monitored appropriately to insure that no long-term adverse environmental effects occurred. Thus, it was contemplated that some form of monitoring should occur related to the first phase--i.e. Amauligak.

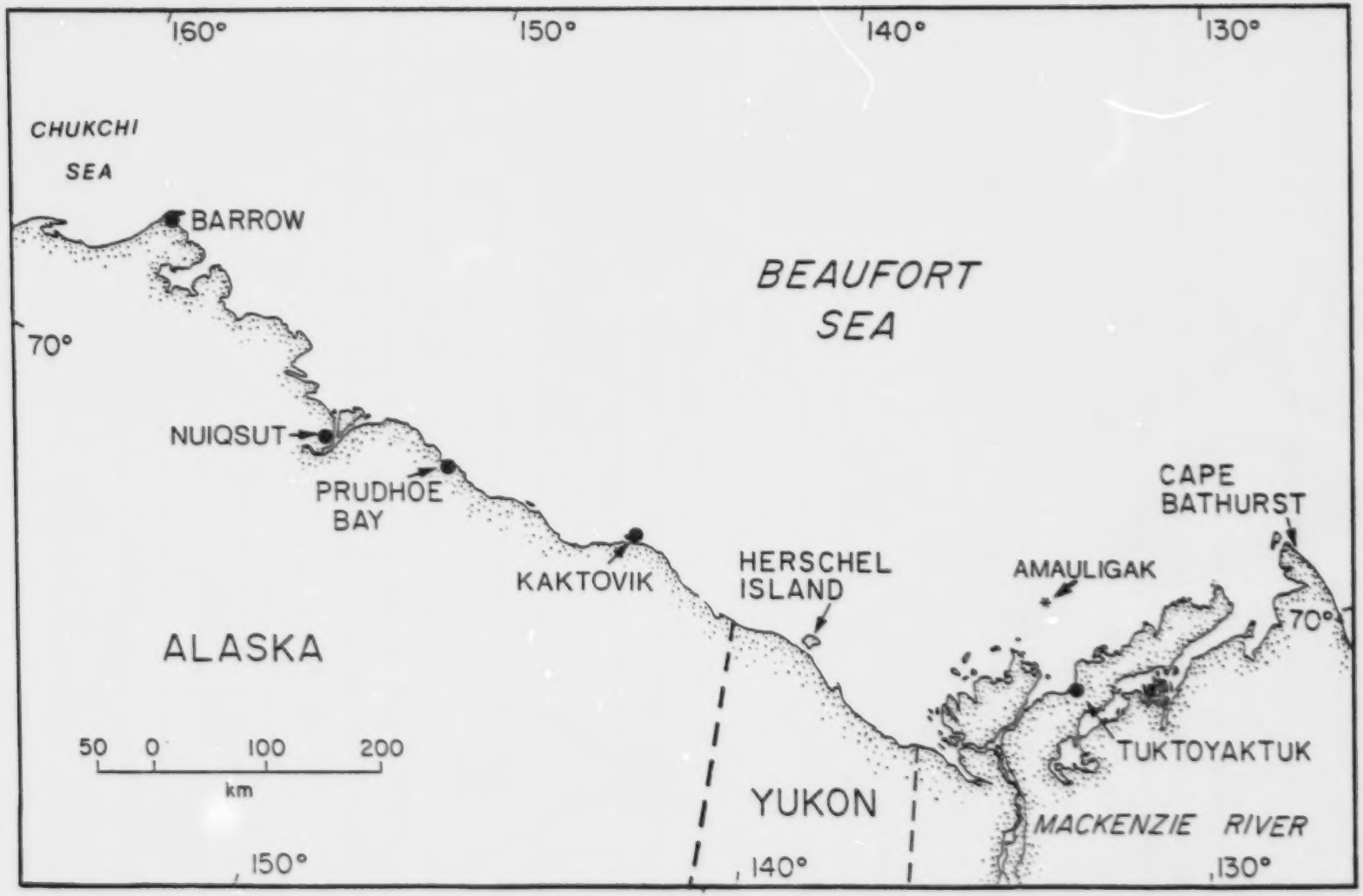


Figure 1. Southern Beaufort Sea area.

A large amount of money (about $20,000,000) has been spent on a wide variety of studies related to the bowhead whale. Many of the studies have been self-contained with results that focused on relatively narrow objectives. In addition, some of the studies have collected large amounts of data that were ancillary to their main objective but which are valuable for other purposes. In some cases, these ancillary data are presented in reports but more often the data have not been published. Taken together, the existing published and unpublished data form a large and valuable source of information to address questions of concern and to plan logical and efficient future studies. We examine this large data base in the following study to address several questions related to assessing the potential effects of the proposed or similar levels of tanker traffic on bowheads.

Several of the major questions addressed in this report were identified by a workshop on the topic during the Beaufort Environmental Monitoring Project (BEMP) sponsored by DIAND and DOE in Victoria, B.C., in March 1987 (DIAND and DOE 1988, in prep.).

The principal topics discussed in the body of this report are

1. Distribution of Calves--It was indicated at the BEMP workshop that, based on observations in 1986, the proposed tanker route from Amauligak may traverse an important calf-rearing area. This is investigated using existing observational data.

2. Age Segregation--There is evidence that age segregation of bowheads occurs on the summering grounds (Davis et al. 1983, 1986a, 1986b; Cubbage and Calambokidis 1987b). It is important to evaluate this segregation to determine if particular segments of the population are more, or less, likely to be exposed to tanker traffic. This question is examined using the available photogrammetric data on whale length.

3. Effects of Age on Bowhead Behavior--Because of the pronounced age segregation that occurs on the summering grounds, it is important to document whether the various age classes have different responses to ship traffic. This

is examined by analysis of the data from quantitative studies conducted by LGL during the 1980-86 period.

4. Photograph File and Data Base--One of the beneficial results of this study is the establishment, in Canada, of a complete inventory of all re-identifiable bowhead photographs from the Western Arctic summering grounds. Similarly, a complete data base to access the photographs and the vast amount of related data has also been created.

5. Micro-scale Movements--In order to study the short-term effects of future tanker traffic on whales, it is necessary to understand the animals' normal short-term behavior patterns. It would be a mistake to attribute movements of bowheads to passing ships if the whale would have moved anyway. The normal, undisturbed short-term movement patterns of bowheads are quantified in this study.

6. Within-Year Site Fidelity--In the previous section we examined the short-term (a few hours) movements of whales. It will be important to determine whether tanker traffic has any longer term (a few days) effects on bowhead distribution. To evaluate this question, it is necessary to document normal patterns of distributional change that occur over these longer periods. In other words, if whales normally move several km over a few day period, then there would be little cause for alarm if similar patterns were to occur after passage of a tanker. Normal patterns of site fidelity are determined by examination of the large numbers of resightings of individually identifiable whales that have been photographed. We also examine the data to discern whether the age of the animal, geographic area, and/or existing industrial activities seem to affect site fidelity and movement patterns.

7. Between-Year Site Fidelity--To determine the effects of tanker traffic, it will be necessary to understand how whales use particular areas from year-to-year. If a particular area is used by the same individuals from year-to-year then disturbance in that area would affect only a limited number of individuals, but the area may be very important to those individuals. If no year-to-year site fidelity is shown, then ship traffic in an area will affect more individuals, but each individual is exposed to traffic fewer times. Year-

to-year site fidelity will be examined by analysis of inter-year photographic matches and year-to-year repeatability of the length distributions (= age structure) of populations in each geographic area.

8. Known Effects of Ship Traffic--A considerable amount of information about the effects of ship traffic on bowhead whales has accumulated during studies begun in 1980. There is no recent summary of the available data. Such a review is necessary to evaluate the potential effects of future tanker traffic. A concise review is presented in this report. This review provides the basis for the following two analyses.

9. Separation of Cow-calf Pairs--The BEMP workshop in March 1987 (DIAND and DOE in prep.) identified the possibility that cow-calf pairs might become permanently separated if tanker noise prevented communication between the cow and the calf. This possibility is examined using available information on whale response to ships, ship noise levels, propagation loss, and potential masking of bowhead calls.

10. Interference with Bowhead Harvests--The BEMP workshop was also concerned that tanker traffic along the Alaskan coast in fall might interfere with the annual fall hunt of whales by the Alaskan Inupiat from Kaktovik and Nuiqsut. The concern is that bowheads could be frightened away from the coast where they are accessible to this shore-based small boat fishery. Conceptual models using information on the known whale responses to ship traffic, the fall distribution of whales, and the distribution of hunting effort are evaluated to determine whether this concern is valid.

1. DISTRIBUTION OF CALVES

The BEMP workshop in March 1987 raised the concern that cow-calf pairs could be detrimentally disrupted by noise from tanker traffic. This issue is discussed in Section 9 of this report. A related question is addressed here: is there any evidence to suggest that the proposed tanker routes traverse important calf-rearing areas? How are calves distributed throughout the summer range and along the fall migration route through the Alaskan Beaufort Sea? Concern about this issue will be increased if a large proportion of the annual calf production is potentially affected by the tankers.

Data Base

The results of 36 studies of bowhead distribution, behavior and length distribution were examined for all valid records of calves. The studies spanned the seven year period from 1980 to 1986 and covered the Alaskan Beaufort Sea east of Prudhoe Bay, the Canadian Beaufort Sea, and Amundsen Gulf. Calves are considered to be young-of-the-year, and are recognizable by their small size, their grayish coloration, and their (usual) close association with their mothers.

A total of 282 bowhead calves were reliably sighted during the 36 studies (Table 1). Of these, 11 calves were observed in Amundsen Gulf, 207 in the Canadian Beaufort Sea, and 64 in the eastern Alaskan Beaufort Sea. Annual survey coverage has been highly variable. Surveys in Canada have sampled areas ranging from 15,000 km^2 in 1980 to 210,000 km^2 in 1981. Annual survey coverage has ranged from 12,000 km to 75,000+ km. These potential biases are discussed where appropriate in the following sections. In addition, some of the differences in calf sightings between years are related to seasonal movements of bowheads and seasonal biases in survey coverage. The seasonal distributions of calf sightings in each area are given in Table 2.

Table 1. Numbers of calves seen during 36 studies in the Beaufort Sea and Amundsen Gulf.

	No. Calves Mapped				
	Alaskan Beaufort	Canadian Beaufort	Amundsen Gulf	Total	Study
1980	-	6	-	6	Renaud and Davis (1981)
"	-	12	-	12	Mirsig et al. (1982)
"	-	5	-	5	Fraker and Fraker (1981)
"	0	0	-	0	Ljungblad (1981)
Sub-total	0	23	-	23	
1981	-	7	0	7	Davis et al. (1982)
"	-	16	0	16	Mirsig et al. (1982)
"	0	0	-	0	Ljungblad et al. (1982a)
Sub-total	0	23	0	23	
1982	5	-	-	5	Johnson (1984)
"	-	57	1	58	Davis et al. (1983)
"	-	16	-	16	Mirsig et al. (1983)
"	-	9[a]	-	9	Harwood and Ford (1983)
"	0	-	-	0	Hickie and Davis (1983)
"	24	12	-	36	Ljungblad et al. (1983)
Sub-total	29	94	1	124	
1983	-	0[b]	-	0	McLaren and Davis (1985)
"	-	5	-	5	Mirsig et al. (1984a)
"	-	8	0	8[c]	Cubbage et al. (1984, this study)
"	5	4	-	9	Ljungblad et al. (1984a)
Sub-total	5	17	0	22	
1984	-	4	8	12	Davis et al. (1986a)
"	-	2	-	2	Mirsig et al. (1985)
"	-	1	1	2[c]	NMFS (Unpubl. data, this study)
"	-	3[d]	0	3	Harwood and Borstad (1985)
"	1	-	-	1	Davis et al. (1985a)
"	2	0	-	2	Ljungblad et al. (1985a)
Sub-total	3	10	9	22	
1985	-	4	1	5	Davis et al. (1986b)
"	4	5	-	9	Richardson et al. (1987b)
"	2	-	-	2	Johnson et al. (1986)
"	0	-	-	0	McLaren et al. (1986)
"	-	0	-	0	Evans and Holdsworth (1986)
"	-	1	-	1	Morton and Harwood (1987)
"	-	1	-	1[c]	Cubbage and Calambokidis (1987a, this study)
"	3	1	-	4	Ljungblad et al. (1986a)
Sub-total	9	12	1	22	
1986	6	15	-	21	Richardson et al. (1987b)
"	9	-	-	9	Koski and Johnson (1987)
"	-	6	-	6	Ford et al. (1987)
"	-	6	-	6[c]	CASCADIA (this study)
"	3	1	-	4	Ljungblad et al. (1987)
Sub-total	18	28	-	46	
1980-86	64	207	11	282	

[a] Ten calves were reported but we were unable to determine the location of one of these.
[b] One calf reported but position not indicated.
[c] The figures shown are based on our analysis of their photographs. The identification of calves was based strictly on morphological characteristics and close association with an apparent adult.
[d] One "tentative" sighting of a calf was not mapped here.

Table 2. Summary of the geographic and temporal distribution of bowhead calf records from the Beaufort Sea and Amundsen Gulf, 1980–86.

Year	Alaskan Beaufort Sea					Canadian Beaufort Sea					Amundsen Gulf					All Areas				
	Seasonal Period[1]					Seasonal Period					Seasonal Period					Seasonal Period				
	1	2	3	4	1–4	1	2	3	4	1–4	1	2	3	4	1–4	1	2	3	4	1–4
1980						9	14			23						9	14			23
1981						3	16	4		23						3	16	4		23
1982	3	3	7	16	29	4	53	33	4	94		1			1	7	57	40	20	124
1983	1	1	2	1	5	10	3	2	2	17						11	4	4	3	22
1984				3	3		8	2		10		4	5		9		12	7	3	22
1985				9	9	1	4	2	5	12	1				1	2	4	2	14	22
1986			7	11	18	1	10	4	13	28						1	10	11	24	46
1980–86	4	4	16	40	64	28	108	47	24	207	1	5	5		11	33	117	68	64	282

[1] 1 = 24 July–15 August, 2 = 16–31 August, 3 = 1–15 September, 4 = 16 September–6 October.

Observed Distribution of Calves

Amundsen Gulf

The distribution of the 11 calves observed in Amundsen Gulf is plotted in Figure 2. Widespread survey coverage in Amundsen Gulf has been conducted in only two years (late July-early September 1981, August 1985). No calves were recorded in 1981 and only one was seen in 1985. The Franklin Bay area has been surveyed more frequently, with photographic coverage in 1982 and 1984 in addition to the survey coverage in 1981 and survey and photographic coverage in 1985. In the four years, calves were common in Franklin Bay only in 1984 (9). A single calf was recorded in 1982. Although adult bowheads regularly occur in Franklin Bay (Davis et al. 1982, 1983, 1986a, 1986b), females with calves were irregular, occurring in only one of four years with substantial aerial coverage.

Canadian Beaufort Sea

A total of 185 calves are mapped in Figure 3. The general impression is that calves occur throughout the Canadian Beaufort Sea except in the 'intense plume' area of turbid, freshened water immediately off the Mackenzie Delta and perhaps in waters far offshore. However, survey coverage offshore north of 71°N has only occurred in 1981 and 1985 and even then coverage was limited. Thus, the apparent absence of calves north of 71°N may be an artefact of the aerial coverage.

Figure 3 indicates that there is much year-to-year variation in the distribution of calves. For example, substantial numbers of calves are mapped north of the Mackenzie Delta and the Tuktoyaktuk Peninsula (Fig. 3). However, the majority of these records occurred in 1980 and 1981 with few calves in these areas in the next five years. Also notable is the large number (82) of calves recorded in 1982 even though coverage was not particularly intense in that year (Davis et al. 1983). Large numbers of females with calves were present off Herschel Island and northeast along the shelfbreak from mid-August to early September in 1982. Almost no calves have been seen in these areas in the other six years of study.

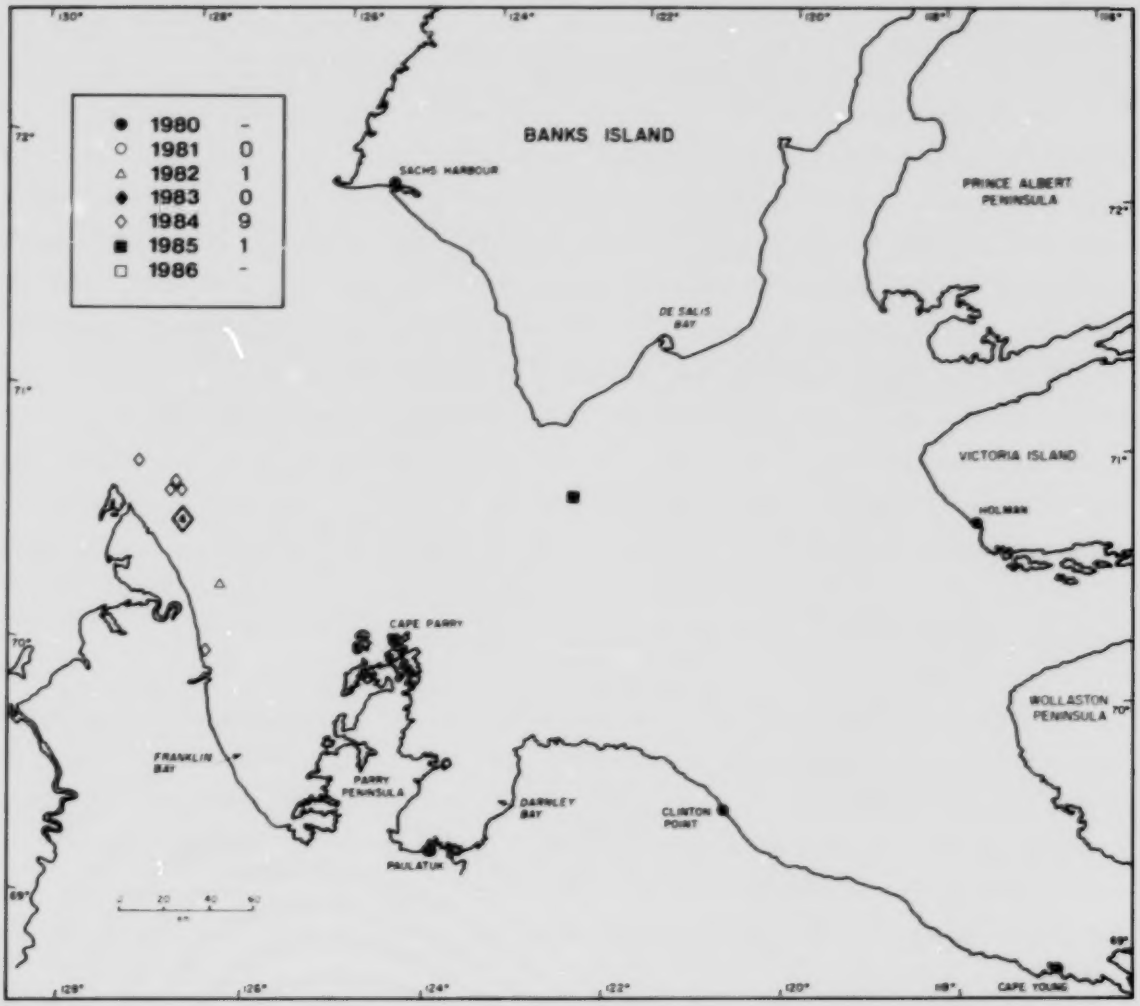


Figure 2. Distribution of bowhead calves recorded in Amundsen Gulf 1980-86 (see Table 1 for details of studies).

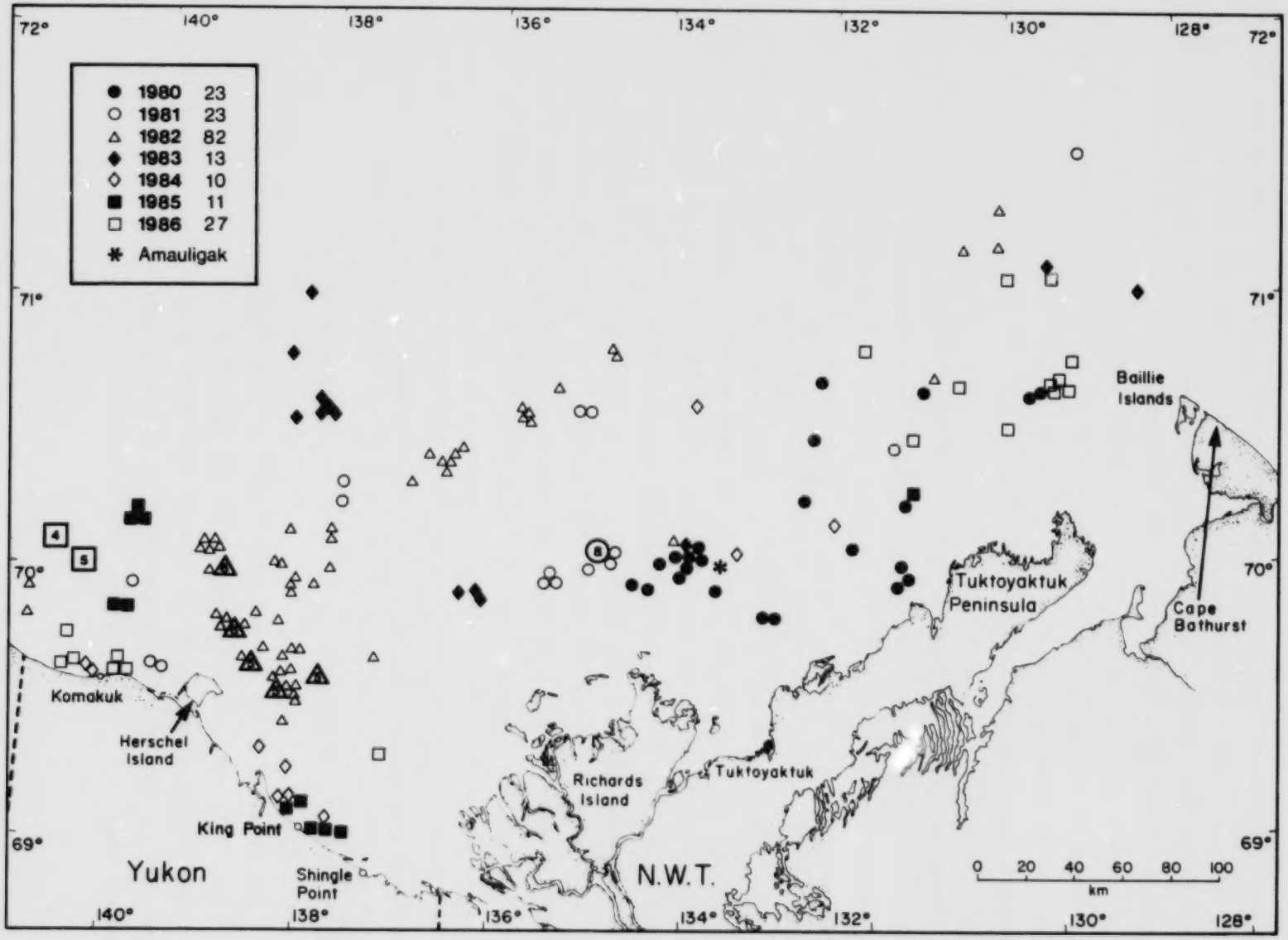


Figure 3. Distribution of bowhead calves recorded in the Canadian Beaufort Sea, 1980-86 excluding Alaska-based surveys by D. Ljungblad, NOSC (Figure 4).

The area northwest of Cape Bathurst is the most regularly used area over the years. At least some calves have been present there in five of the six years with coverage. Calves were present in four years off the Yukon coast east of Herschel Island. However, this area has been the subject of very intensive photographic and survey coverage and the number of calf sightings is actually very small in proportion to the study effort and as a percentage of the numbers of whales in the area. Photographic studies have shown that most of the large numbers of whales off the eastern Yukon coast are non-breeding subadults (see Section 2, later).

Bowheads occupy the waters west of Herschel Island in late summer and during fall migration, primarily in September and early October. The distribution of calves west of Herschel Island as determined by Canadian-based studies is shown in Figure 3. The results of seven years of the intensive MMS-funded monitoring surveys of the Alaskan and extreme western Canadian Beaufort Sea are presented in Figure 4, where 55 calves are mapped. In addition, 27 calves recorded during LGL studies in the Alaskan Beaufort Sea are mapped in Figure 5. In the waters north of Komakuk substantial numbers of calves were noted in 1985 and 1986 during Canadian-based studies in September. As was the case farther east in Mackenzie Bay, only a very small proportion of the many whales close to shore near Komakuk in 1985-86 were calves (or adults). A much larger proportion of the smaller number of whales offshore from Komakuk were calves, most of which were seen in late September during migration (Richardson et al. 1987b). The parts of the area north of 70°N were not intensively covered in previous years and it is not known whether they supported large numbers of calves in previous years.

Eastern Alaskan Beaufort Sea

The great majority of the calf sightings from Alaska were in 1982, 1985 and 1986. This pattern is influenced by the fact that LGL studies as well as NOSC/MMS studies occurred in Alaska in those years. The overwhelming importance of 1982 for calves was noted in Alaska as well as in the Canadian Beaufort Sea.

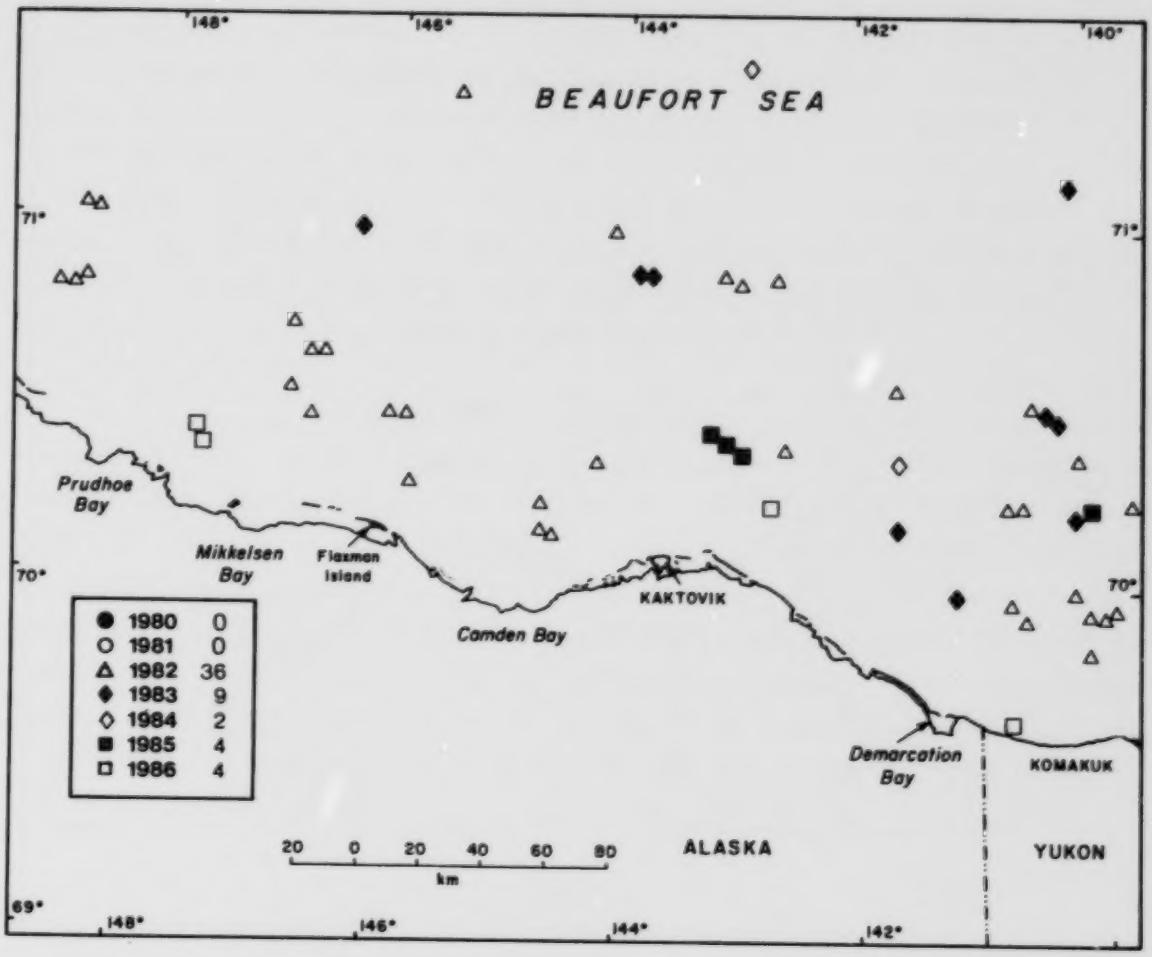


Figure 4. Distribution of bowhead calves (55) recorded during U.S. MMS-funded surveys conducted in 1980-86 by D. K. Ljungblad of NOSC and co-workers (see Table 1 for details). Eighteen of the calves were in Canadian waters west of 139°30'W.

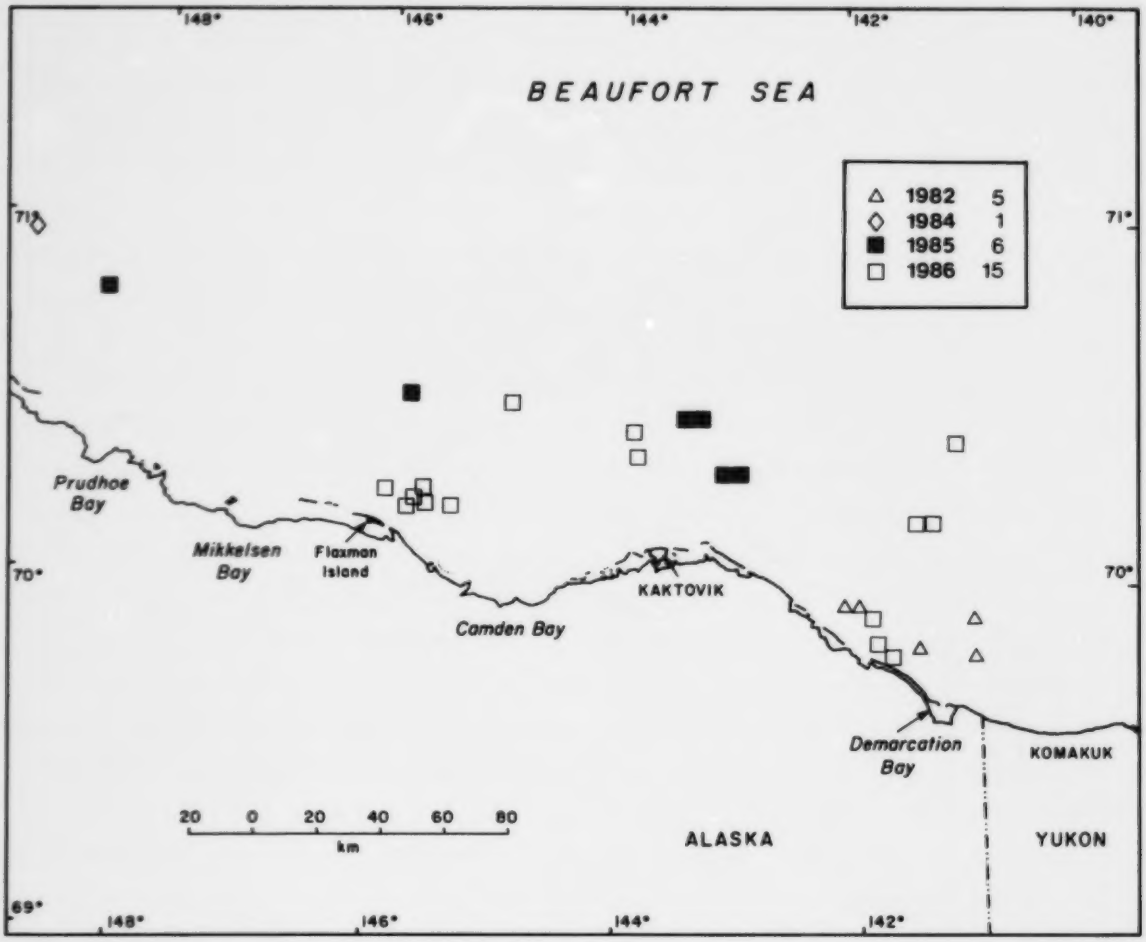


Figure 5. Distribution of bowhead calves (27) recorded in the eastern Alaskan Beaufort Sea in 1982 and 1984-86 during LGL Limited surveys.

No striking concentrations of calves have been found in the eastern Alaskan Beaufort Sea (Figs. 4 and 5). The distribution of sightings offshore is thought to be a function of survey coverage. The LGL surveys did not extend as far offshore as the NOSC/MMS studies. Thus, the apparent distribution of calves extends less far offshore in Figure 5 than in Figure 4. Clarke et al. (1987) thought that calves were distributed more or less the same as the population as a whole during fall migration through the Alaskan Beaufort Sea. However, this was not true near the coast in 1985-86. Richardson et al. (1987b) noted that calves were rare among animals recorded in shallow water along the coast, but that they were more common offshore.

There have been relatively few bowhead calves recorded in Alaskan waters in spite of quite intensive coverage of fall migration from 1979 to 1986. From 1980 to 1986, the period considered here, only 64 calves were noted; fully 29 (45%) of these were seen in 1982. On average, fewer than six calves were recorded in each of the other six years of coverage. Thus, the nearshore band along the north coast of Alaska does not imply that the Alaskan Beaufort is unimportant for calves, only that the calves do not appear to be concentrated in any particular area or water depth. It is assumed that most of the population, including calves, migrates through the Alaskan Beaufort Sea in fall.

Summary

The distribution of bowhead calves is highly variable from year-to-year with most parts of the Canadian Beaufort Sea and Amundsen Gulf used only sparingly or in a minority of years. Females and calves occur regularly northwest of Cape Bathurst. In most years calves are rare in surveyed areas during August, but become more common in early September and even more common in nearshore and especially offshore areas in late September. Calves are widespread, but not concentrated during fall migration through the eastern Alaskan Beaufort Sea. Thus, a tanker route extending west from Amauligak is unlikely to encounter any particularly important calf-rearing area. In seven years with data, large numbers of calves would have been exposed only in 1982.

In that year large numbers of calves occurred northeast of Herschel Island during late summer (Fig. 3) and in Alaska during fall migration.

The potential effects of tankers on those calves that are exposed to tanker noise are discussed in Section 9 of this report.

2. AGE SEGREGATION

Previous studies conducted in the Beaufort Sea have found considerable variation in the size distribution of whales during different years and in different geographic areas. However, data from each of these studies have been presented on a study by study basis, which does not permit a comprehensive evaluation. Here we bring together the available length data from all eastern Alaska and Canadian Beaufort Sea summer and fall studies. The geographic subdivisions on which all of the following discussions are based are shown in Figures 6-8.

Definitions of Size and Age Classes

Four different age classes of bowhead whales have been recognized during previous studies. These size classes are calves, small subadults, large subadults and adults.

Calves

Bowhead whales are considered to be calves during their first year of life. Since birth occurs in spring and early summer, calves observed in July-October during the studies considered here were <8 months old. Davis et al. (1983) assumed that all whales smaller than 7.6 m were calves based on their length frequency data. More detailed analyses by Davis et al. (1986a,b), which considered morphological characteristics of calves and subadults in the photographs, found that all whales smaller than 7.0 m were calves, one-third of whales 7.0-7.5 m in length were calves and only one whale >7.5 m was a calf. These analyses included whales photographed from early August to mid September but did not include any calves photographed after 14 September. Richardson et al. (1987b) photographed 19 calves near Komakuk from 14-29 September in 1985 and 1986. Although their mean calf size was larger than found during earlier studies, none of their calves were larger than 7.5 m.

In summary, during August and September virtually all calves are <7.5 m in length but many of the whales between 7.0 and 7.5 m are yearlings. We distinguished calves from small subadults by considering coloration, body

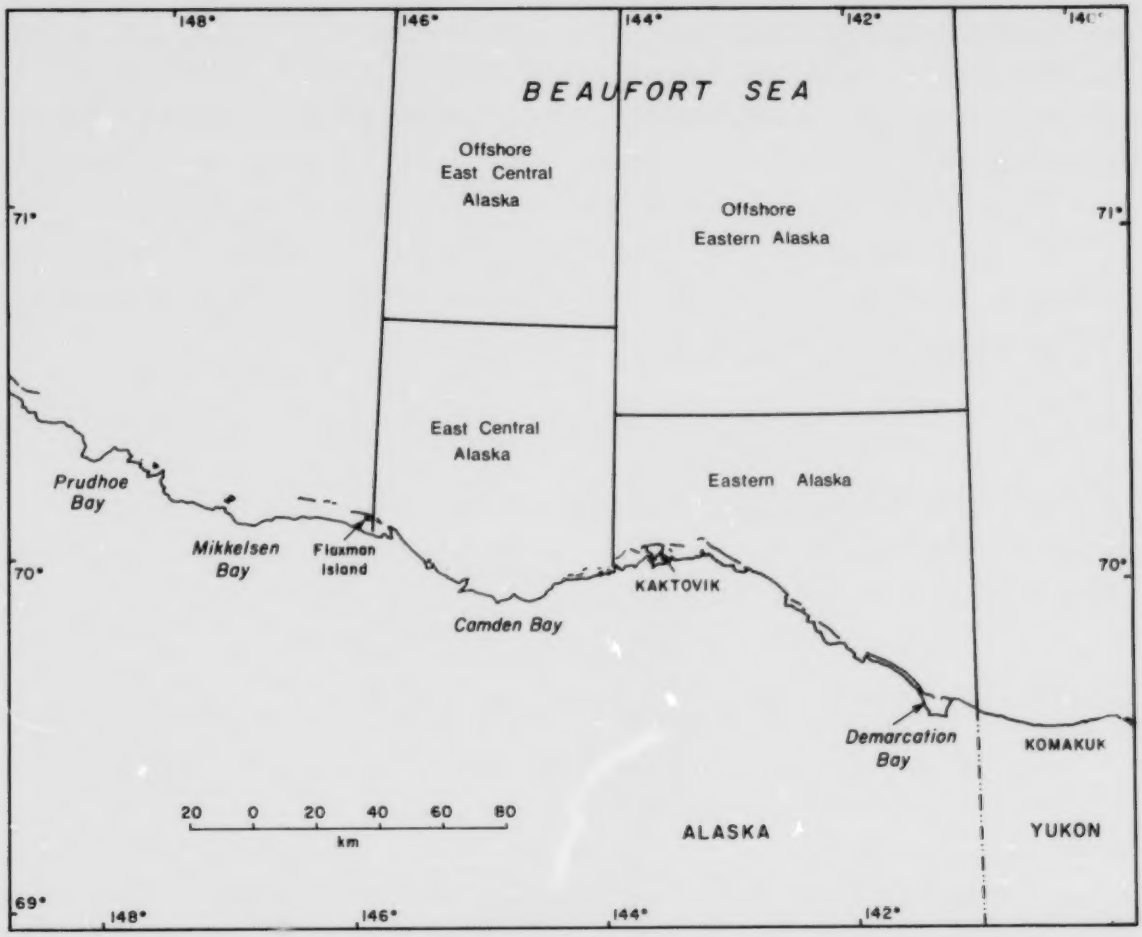


Figure 6. Locations of survey blocks where bowhead whales were photographed in the eastern Alaska Beaufort Sea.

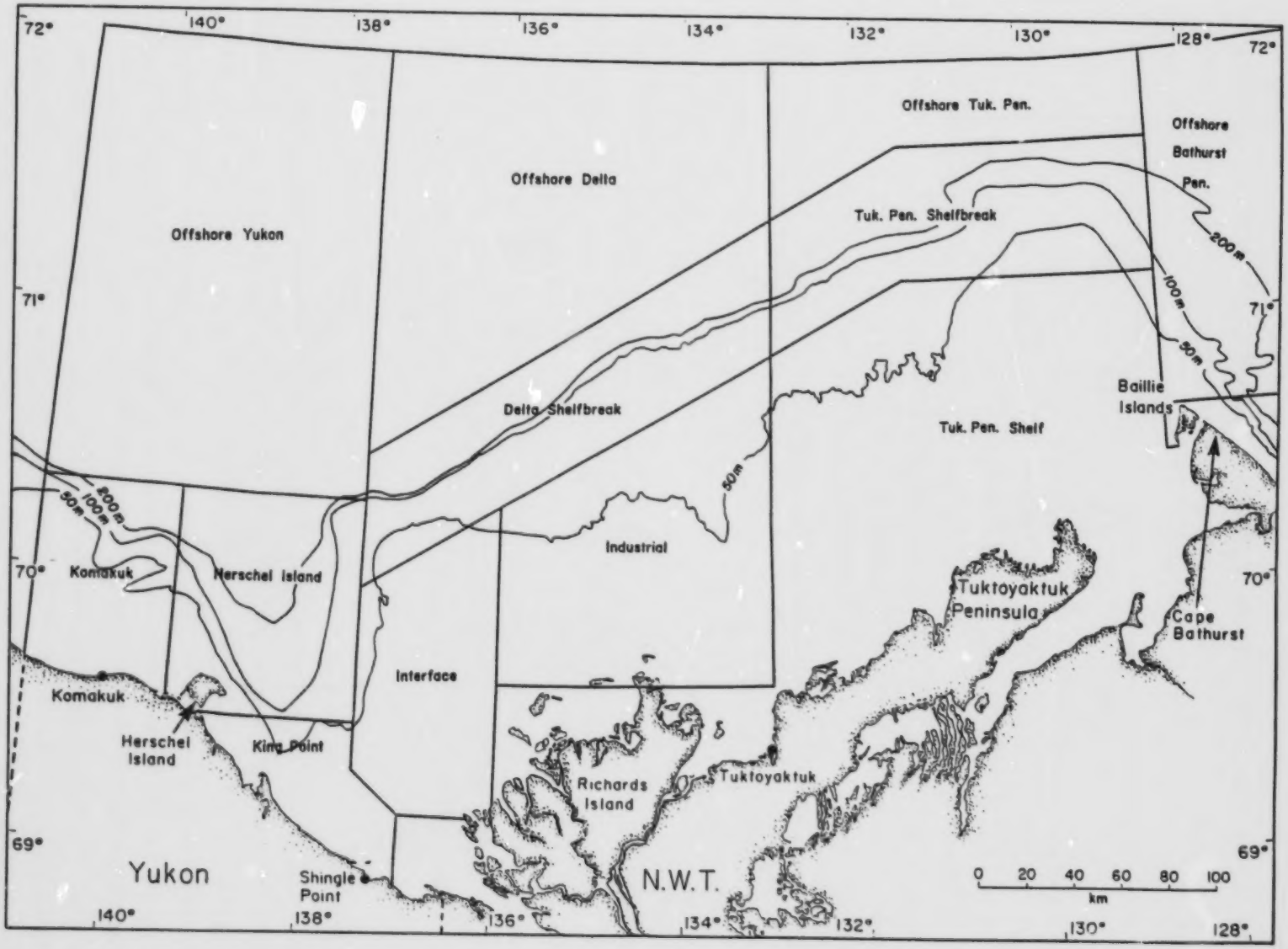


Figure 7. Locations of survey blocks where bowhead whales were photographed in the Canadian Beaufort Sea.

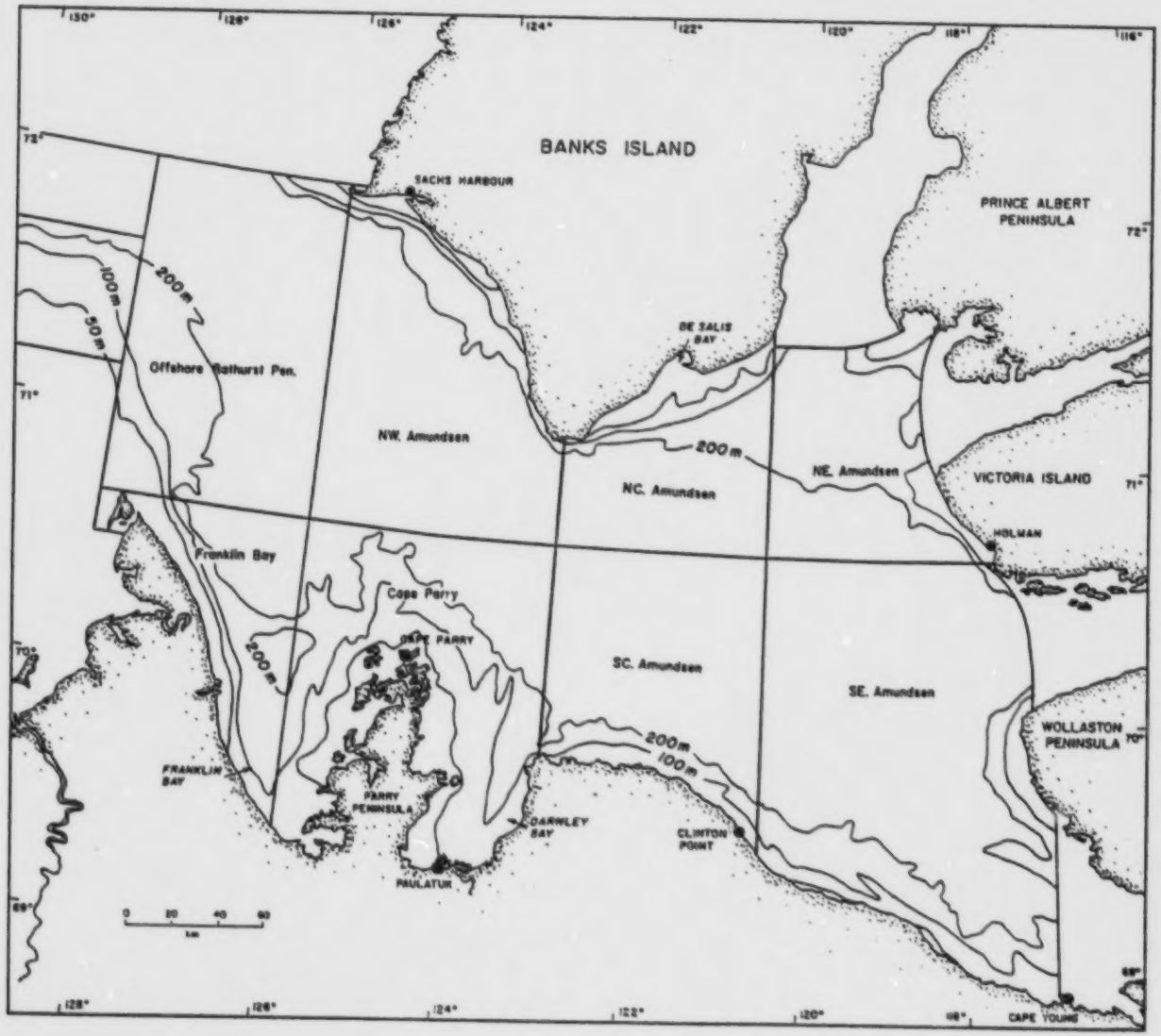


Figure 8. Locations of survey blocks where bowhead whales were photographed in Amundsen Gulf.

proportions, and association with a large whale (the mother) as well as by size per se. If we were unable to 'confirm' whether an animals was a calf by these criteria, it was not considered to be a calf.

Small Subadults

Non-calf subadults <10 m have been referred to in previous studies (Davis et al. 1986a; Richardson et al. 1987b) as small subadults. Nerini et al. (1984) believed that yearlings in September could exceed 10 m but recent photogrammetric data (Appendix V in Davis et al. 1986b) and recent isotope analyses of bowhead whale baleen (Schell et al. 1987) suggest that 10 m whales are much older than 1 year. The growth rates of subadult bowheads and the age composition of bowheads <10 m long are controversial and require further investigation. Operationally, however, it is useful to continue to recognize that <10 m size class as small subadults.

Large Subadults

This group contains whales 10-13 m in length. The 10 m cutpoint is arbitrary, as note above. The 13 m cutpoint is based on the size at which bowheads typically become capable of reproduction. Because of individual variability in size at maturity, some of the larger (>12 m) animals classed as large subadults may be breeding females or males and hence adults (see below). We consider all bowheads 10-13 m in length to be large subadults.

Adults

Adults are animals that are reproductively mature. Davis et al. (1983) found that 22% of the whales longer than 13.5 m were accompanied by calves, but that only 2.2% of whales 12-13 m and 3.7% of whales 13-13.5 m long were accompanied by calves. Biological sampling studies have substantiated these results but only seven sexually mature females were examined by Nerini et al. (1984) and 10 by Tarpley (1987). The smallest mature female examined by Nerini et al. (1984) was 14.2 m, but no whales between 11.5 and 14.2 m in length with complete ovaries were examined. Tarpley (1987) found immatures as large as 14.4 m and his smallest mature female was 14.7 m. The smallest adult

photographed with a calf (12.2 m in 1982) was rephotographed in 1984 and found to be 12.5 m long, confirming her small size and indicating that some whales smaller than 13 m are sexually mature. Thus, we use 13 m as the dividing line, although we recognize that some adults are less than 13 m and that some animals larger than 13 m are not adults.

Overall Size and Age Distributions

Several potential sources of bias should be mentioned before presenting the length data. In the following sections the length of each whale is presented once for each study during which it was photographed; within study repeat measurements have been removed. A few individual whales are represented more than once within the same year if they were photographed during two studies.

It was necessary to eliminate within study repeat measurements to reduce the biases caused by the different objectives of the different studies. For example, the 1982 study (Davis et al. 1983) attempted to minimize repeat photographs while the 1984 study (Davis et al. 1986a) attempted to rephotograph the same whales. The elimination of within study repeats will overemphasize small whales in length-frequency distributions because duplicate images of small whales are less likely to be recognized than are photographs of large whales (Davis et al. 1983, 1986a).

The proportion of calves may also be biased slightly upwards. Davis et al. (1983) found that calves are more likely to be photographed, but less likely to be measured than non-calves. The net effect is that calves are slightly more likely to be measured than non-calves. In addition, it is possible that some researchers put extra effort into photographing cow-calf pairs.

Overall, 1988 length measurements were available for the following analyses. Figure 9 shows the frequency distribution of these lengths. Only 86 (4.3%) of all whales photographed were 'confirmed' calves. This estimate is conservative because three whales 6.5-7 m in length and several whales 7-7.5 m in length that were considered potential calves were excluded. If all whales

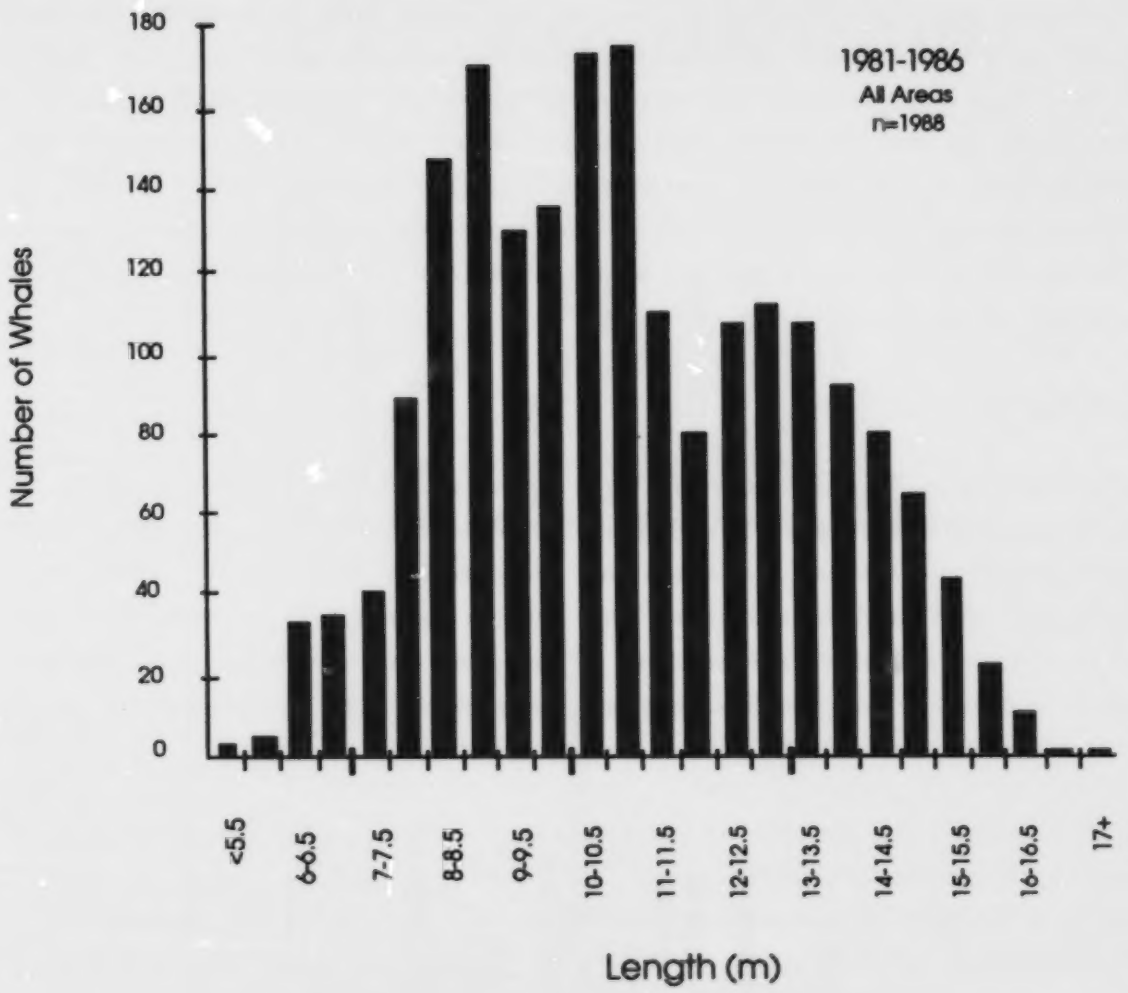


Figure 9. Length frequency distribution of bowhead whales photographed in the eastern Alaska and Canadian Beaufort Sea and Amundsen Gulf 1981-1986. Known within-study duplicates are excluded but each individual whale is included once for each study during which it was photographed.

<7 m and 33% of whales 7-7.5 m are considered calves, the number of calves becomes 93 (4.7%).

A total of 432 whales were classed as adults. Assuming that calves and adults were equally photographable, about 19.9-21.5% of the adults (86 or 93/432) were accompanied by calves. Because adult female bowheads are suspected to have a calf only once every 3-4 years, and because females constitute approximately half of the adult animals, only 12.5-16.7% of adults would be expected to be accompanied by calves. It appears then that adults with calves are more heavily represented among photographed whales than are other adults. On the other hand, adult whales appear to be greatly under represented in the sample of measured whales; they represent only 23% (432) of all whales excluding calves (1896 or 1903 depending on how many are counted as calves, see above) or 22% of all measured whales. Further discussion of adult segregation appears in later sections.

Year-to-Year Differences

Considerable year-to-year differences are evident in the lengths of whales photographed (Fig. 10). The whales photographed during the 1981 study were primarily adults, whereas those photographed during 1983, 1984, four different 1985 studies and three 1986 studies were primarily subadults. The 1982 distribution differs from those of all other years because relatively few small subadults were photographed and relatively high proportions of both large subadults and adults with calves were photographed.

A second point to note is the considerable variation in the proportion of calves in photographs among years. This variation may be caused by several factors including seasonal differences in the timing of photography, photography of different geographic regions during different years, differences in cow-calf distribution between years, and year-to-year variation in calf production. The percentage of 'confirmed' calves varied from 11.7% in 1982 and 8.2% in 1986 to 1.2-1.4% in 1981, 1984 and 1985. This year-to-year variation in sightings of calves should be considered when interpreting seasonal and geographic patterns of calf distribution and numbers.

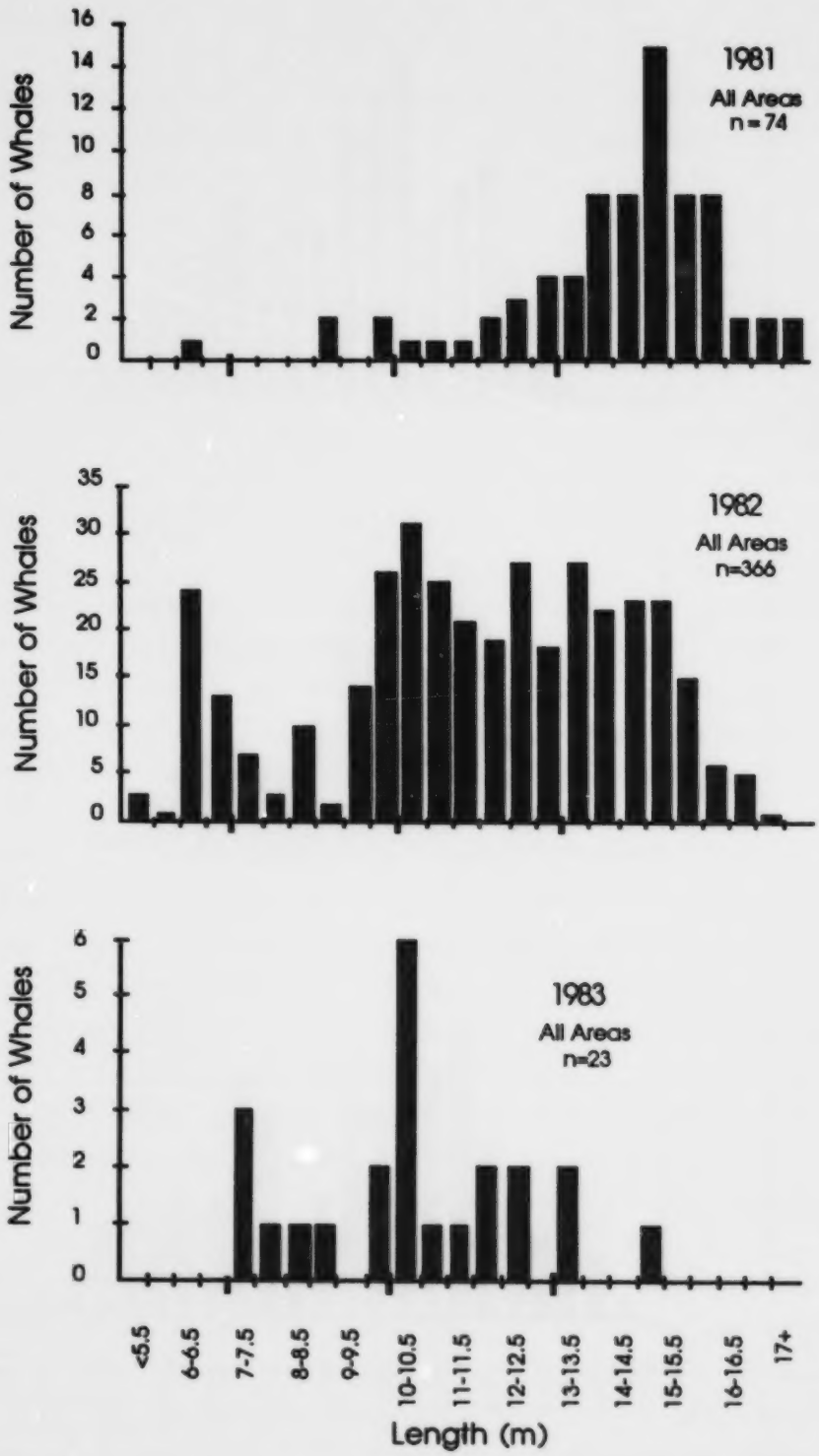


Figure 10. Length frequency distributions of bowhead whales photographed in the eastern Alaskan and Canadian Beaufort Sea and Amundsen Gulf in each year from 1981 to 1986.

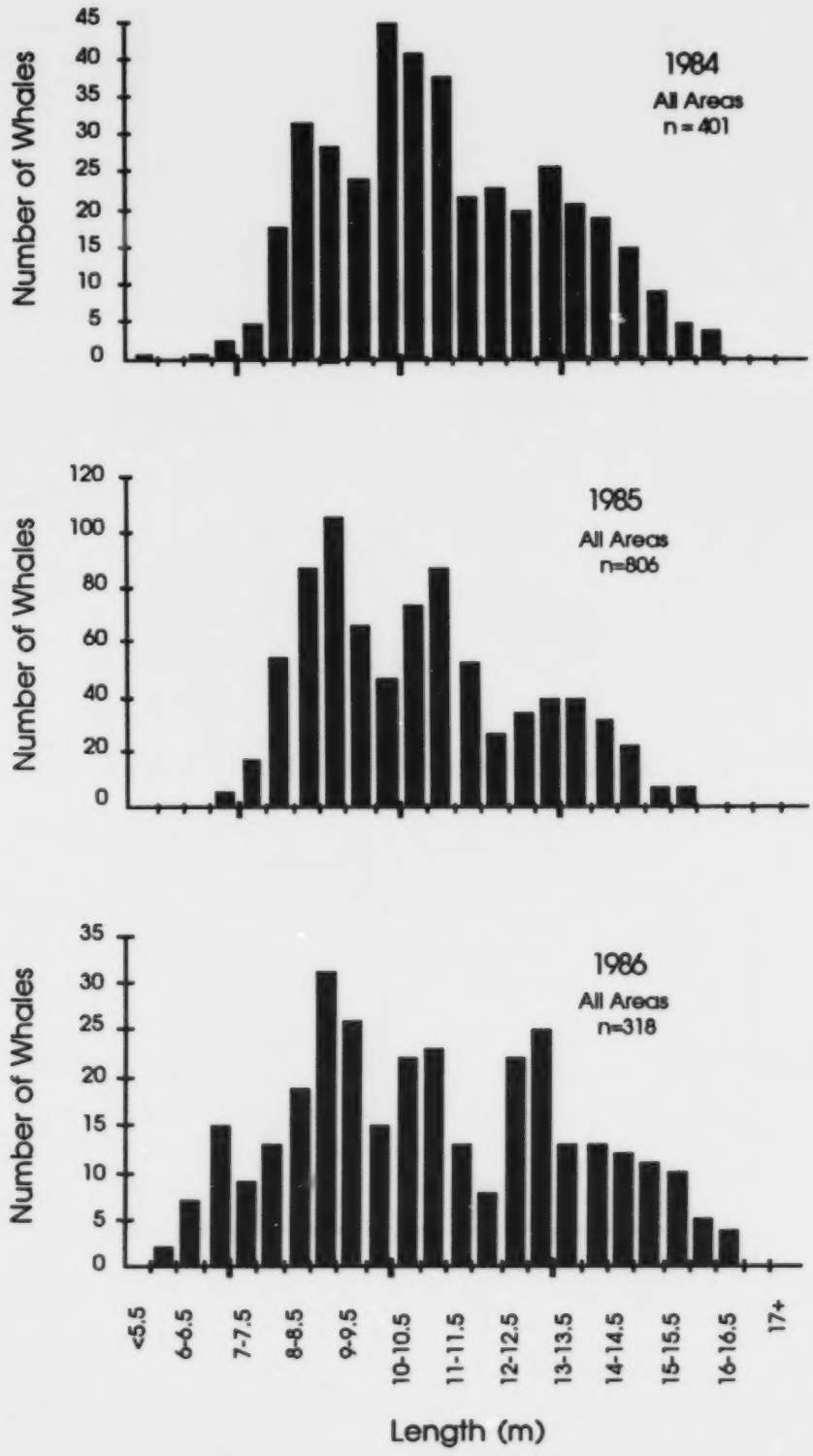


Figure 10. Cont'd.

Seasonal Differences

The seasonal changes in the length-frequency distribution of whales photographed are dramatic and reflect the seasonal movements (and therefore the availability to photographers) of different components of the populations (Fig. 11). Photogrammetric studies have generally attempted to photograph whales whenever and wherever they were found, although, because of logistic restraints, more effort has been expended in nearshore than far offshore areas.

Few whales have been photographed during July because whales are dispersed among the pack-ice far offshore. The few whales photographed, all in 1981 have been primarily adult whales (Fig. 11).

During early August of some years bowheads start to move into coastal areas (Richardson et al. 1987a). At this time they also are common in Amundsen Gulf. Forty-four percent of the whales photographed in early August have been adults but few (3.4%) were accompanied by calves (Fig. 11; Appendix 1). The rest of the measured whales were split equally among small subadults (34 or 26%) and large subadults (37 or 28%).

Large numbers of bowheads have moved into nearshore areas by mid to late August in most years. Over half of all length measurements obtained have been during mid-to-late August. Adults made up only 18% of the measured whales during this period, but 18% of these adults were accompanied by calves (Appendix 1). Calves constituted 3.4% of the measured whales in mid-to-late August. Small and large subadult whales each made up 39% of all whales photographed. However, over half of the 'large' subadults were 10-11 m so non-calves 11 m or smaller made up 59% of measured whales in late August.

The length distribution of whales measured in early September was similar to that in late August (Fig. 11). The proportion of calves was similar--3.4% in late August and 4.3% in early September. There was an increase in the percentage of adults accompanied by calves from 18 to 22%. Adult whales comprised about the same proportion of measured whales during early September (19%) as during late August (18%, Appendix 1).

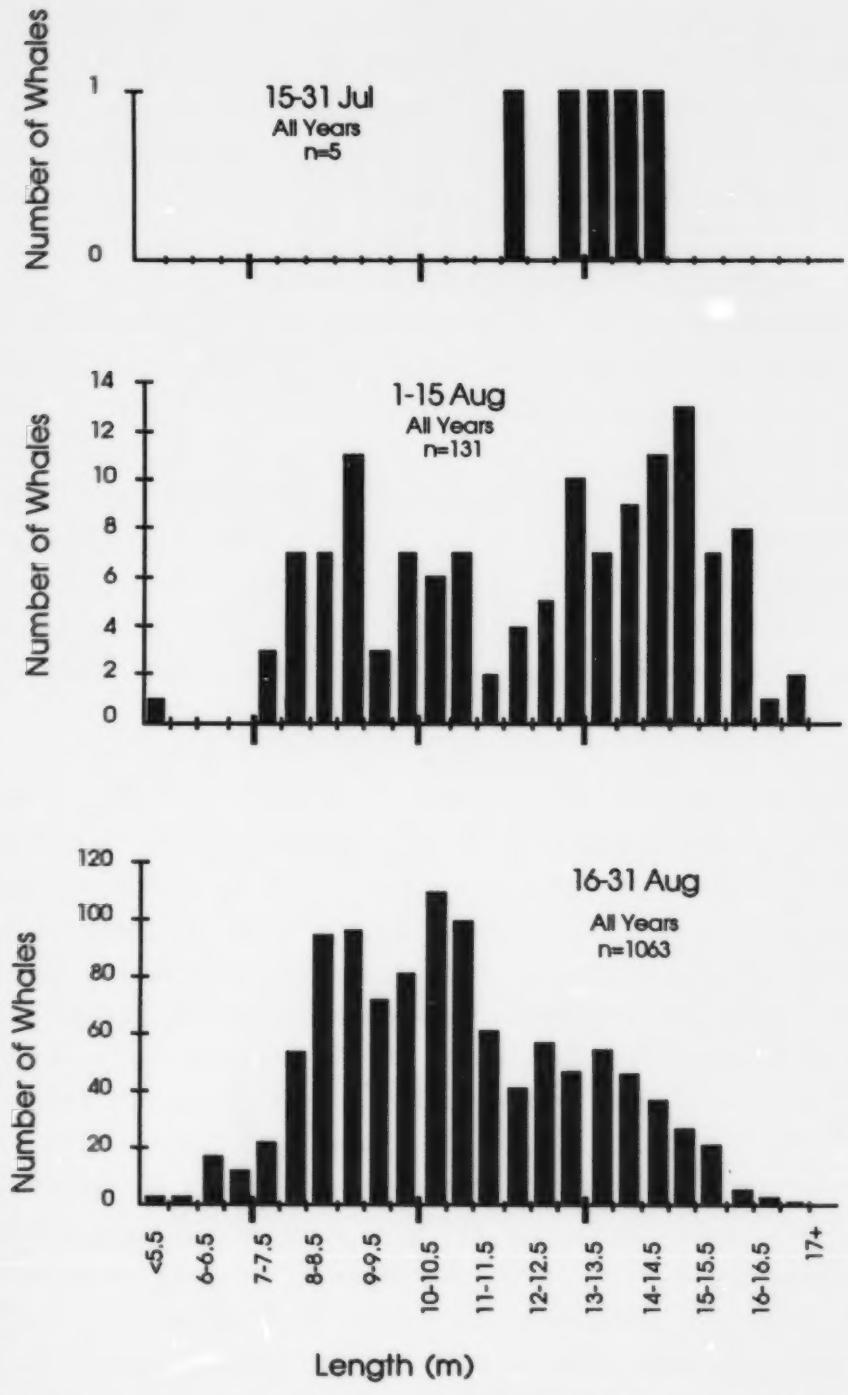


Figure 11. Length frequency distribution by half month periods of bowhead whales photographed in the eastern Alaskan and Canadian Beaufort Sea and Amundsen Gulf 1981-1986.

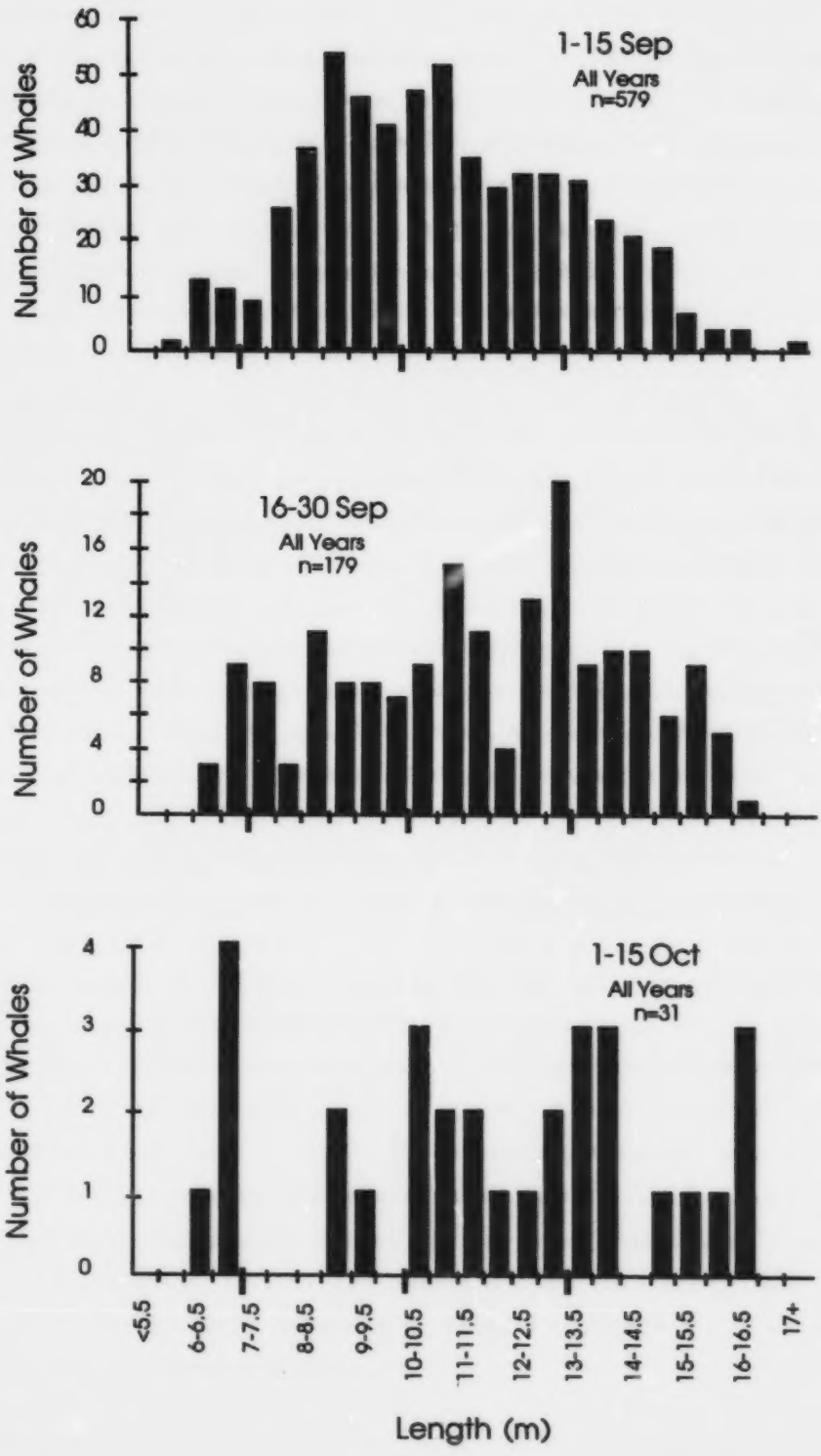


Figure 11. Con't.

The relatively small number of measured whales in late September came from only two years--1985 and 1986. The proportion of small subadults in the sample was reduced almost in half to 22% and the proportion of calves increased from 4.3% during the previous period to 10.1% of all whales measured during this period. Adults made up 28% of the measured whales and 36% of these adults were accompanied by calves (Appendix 1). Large subadults made up 40% of the measured whales. Futhermore, these large subadults included proportionately more 'pre-adults' (i.e. 12-13 m) than were photographed earlier in the year. Thus, the size composition of whales photographed in late September, when migration was underway differed from that in mid-August to mid-September.

Most bowheads have left the eastern Beaufort Sea by early October. The few whales measured during early October, all of which were measured in the Alaskan Beaufort in 1985-86, likely represent the latter stages of migration. These late migrants consist primarily of large subadults (35%) and adults (39%) accompanied by calves (16%; Fig. 11). It is interesting that 42% (5) of the 12 adults photographed during this period were accompanied by calves. If this pattern applies to larger samples, then it suggests either that adults with calves migrate closer to shore and are therefore more likely to be photographed than other adults or that they migrate later (or more slowly) than other adults.

Geographic Differences in Size and Age Distributions

In addition to year-to-year and seasonal variation, the length-frequency distributions exhibit pronounced geographic variations. The following sections discuss the bowheads found in each of the geographic subdivisions of the study area shown in Figures 6-8. Only subdivisions where 10 or more length measurements were obtained are discussed. Thus, the offshore subdivisions and the whale measurements from these areas are excluded from the following section.

East Central Alaska

Adult bowheads formed a much higher proportion of the whales measured in the East Central Alaska region (50%, Fig. 12) than of all whales measured (22%, Fig. 9; Appendix 1). Although the total number of measured whales for this area was very low, a high proportion (5 of 26 or 19%) of the measured whales were calves. Photographs obtained in this area were obtained primarily during the migration period in early October, mainly during 1986 when calves were relatively common (8.2% of all measured whales in 1986 were calves).

Eastern Alaska

Overall, adult bowheads formed a smaller percentage (30%, Fig. 13) of the measured whales in eastern Alaska than in east central Alaska (50%, Fig. 12; Appendix 1). The difference was attributable to seasonal and year-to-year differences. The whales off Eastern Alaska during the first half of September included only 15% adults, whereas those photographed during the second half of September were 52% adults (Fig. 14). The latter figure is very similar to the 50% value off East Central Alaska in late September and October. During 1985, 40% of the measured whales off Eastern Alaska were adults; in 1986, only 20% were adults (Fig. 13). The overall difference between the Eastern and East Central areas was due to the presence of a feeding concentration of subadult bowheads in shallow water in Eastern Alaska during early September of 1986 (Richardson 1987b). Calves constituted 10.9% of all measured whales in Eastern Alaska; they formed 7.7% of all whales in early September and 16% of all whales in late September when many adults and calves were migrating west through the area.

Komakuk

The Komakuk area has been intensively surveyed, particularly during 1984-86. A total of 318 whale lengths are available for this area. Only 13% of all whales measured in this area were adults (Fig. 15; Appendix 1), which is lower than the 22% for all areas combined.

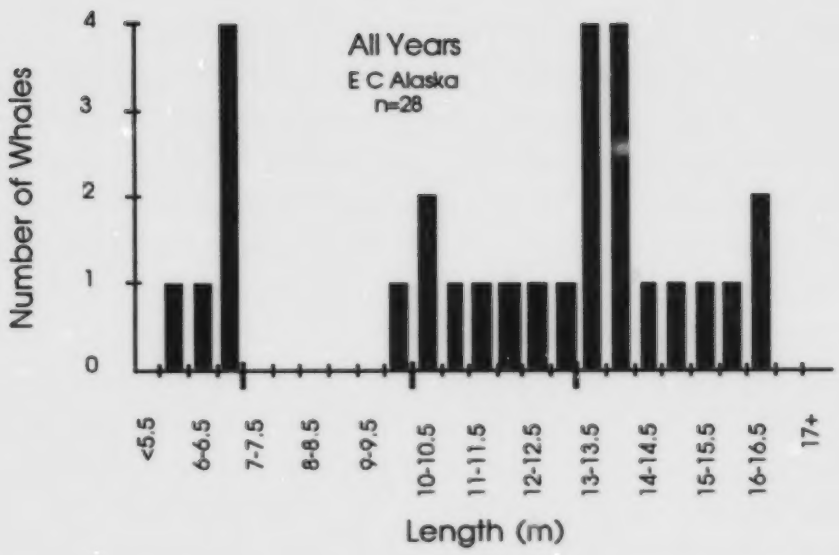


Figure 12. Length frequency distribution of bowhead whales photographed in East Central Alaska in 1985 and 1986.

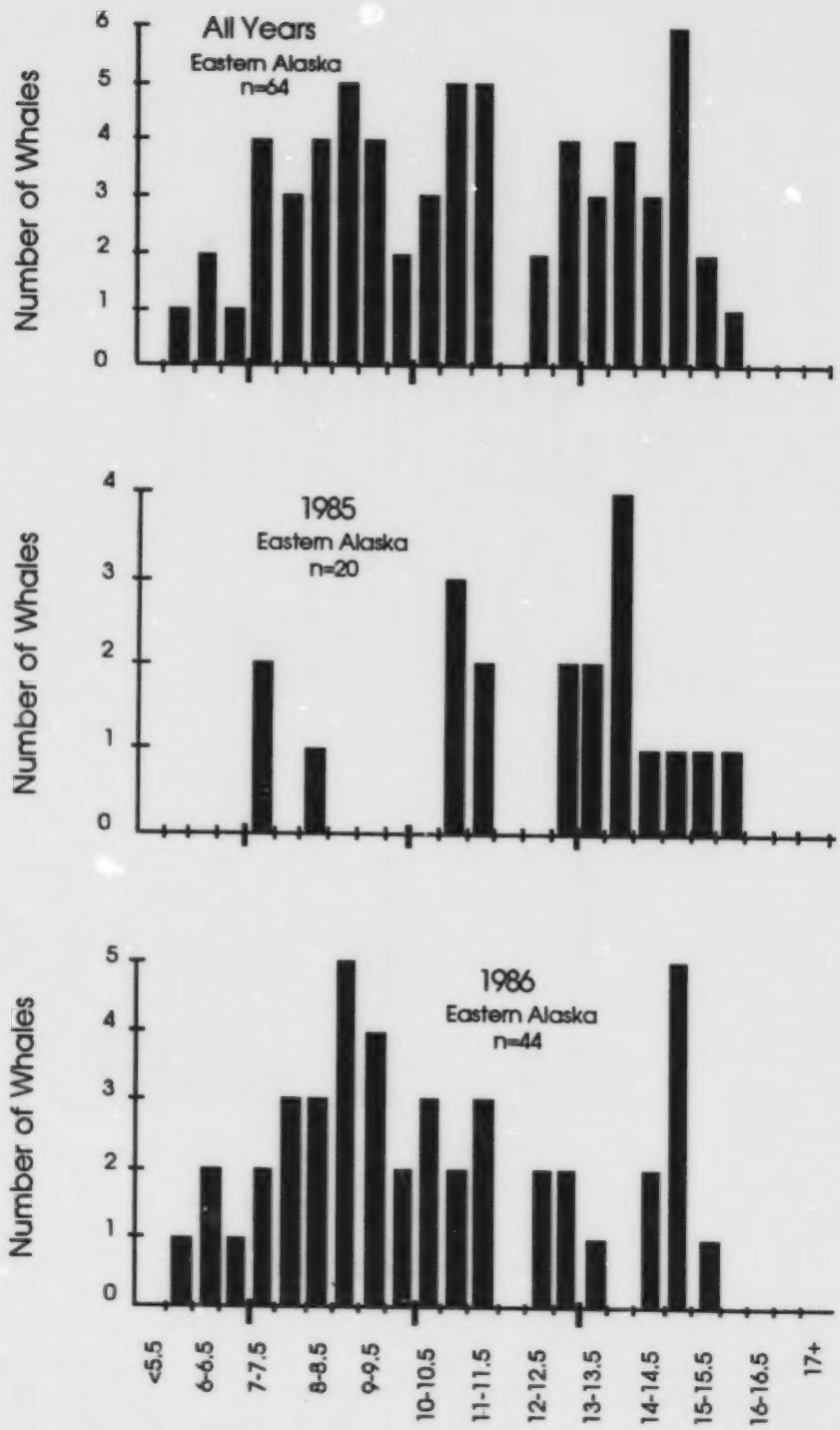


Figure 13. Length frequency distributions of bowhead whales photographed in Eastern Alaska in 1985 and 1986.

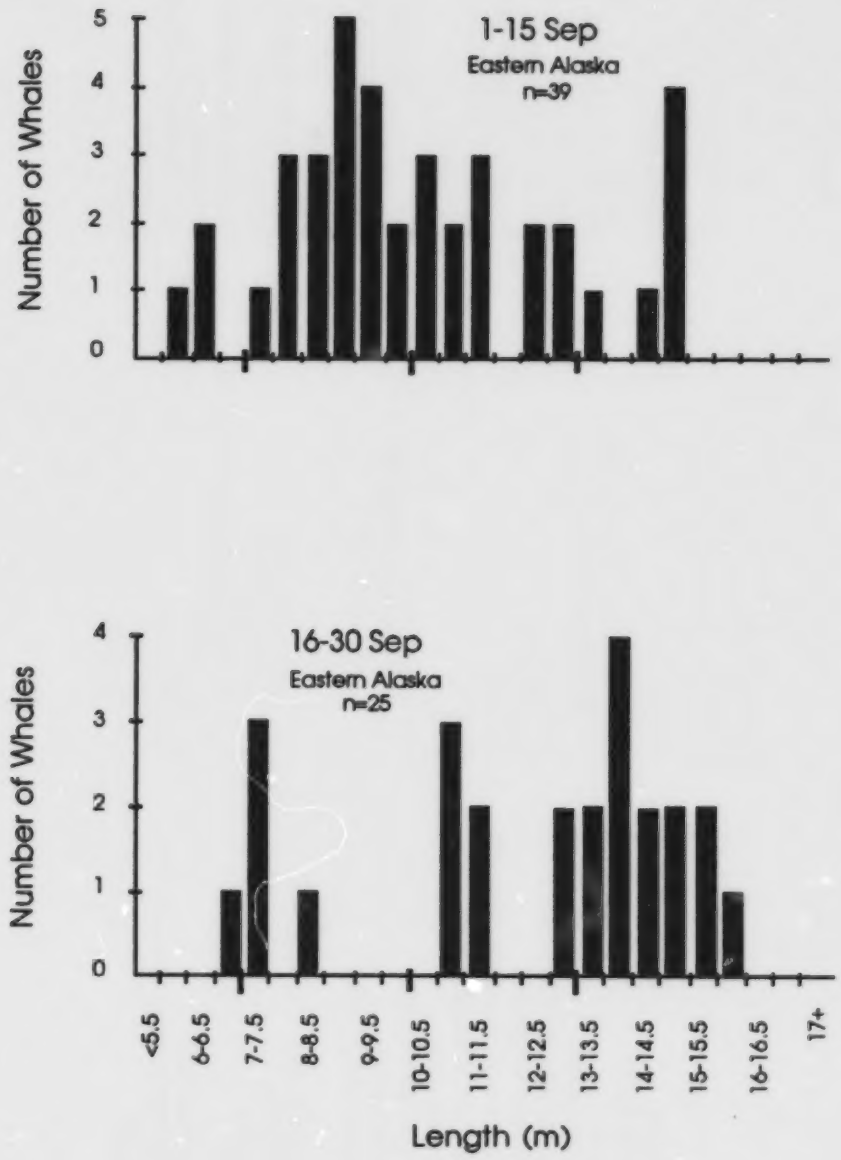


Figure 14. Length frequency distributions of bowhead whales photographed in Eastern Alaska in early and late September.

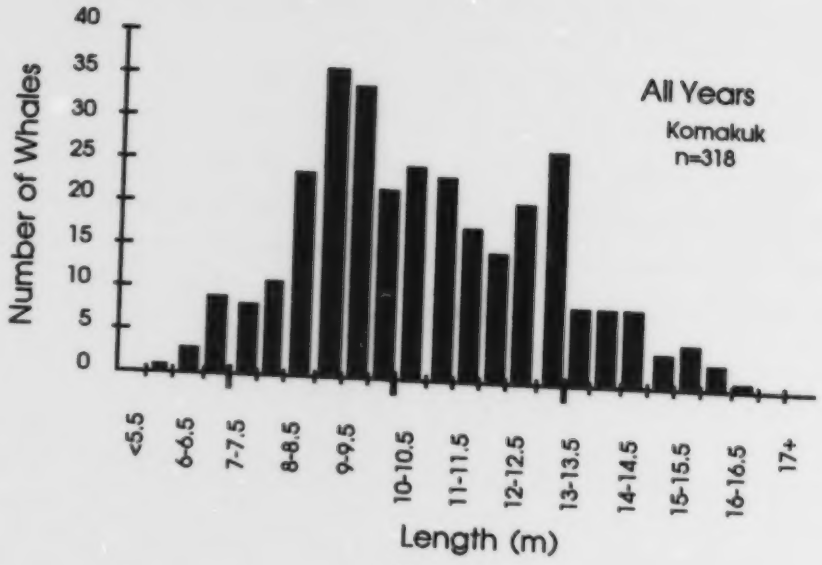


Figure 15. Length frequency distribution of bowhead whales photographed near Komakuk.

Adults constituted similar proportions of the whales photographed near Komakuk in each year from 1984-86. However, large subadults formed a much higher proportion of those present in 1986 than in 1984-85, and small subadults formed a corresponding lower proportion (Fig. 16). This may have been a result of the slightly different seasonal timing and geographic distribution of the 1986 photography. Figure 17 shows that during late August and early September most of the whales present were small subadults 8-10 m in length. Most of these whales were in shallow nearshore waters. By late September fall migration has started and the whales measured during late September ranged from calves to large adults (Fig. 17). Only one calf was measured in each of the late August (1.7%) and early September (0.9%) but 13 calves (8.7%) were measured in late September. Most of the calves and adults were well offshore (Richardson et al. 1987b). This seasonal change in size distribution is consistent with length measurements from the Alaskan areas to the west of Komakuk.

Herschel Island

The Herschel Island zone included the second largest number (407) of measured whales of all areas considered during this study. A large proportion (71%) of the measurements from this area were obtained in 1982. Nevertheless, this area still has the most complete year-to-year coverage of all areas photographed (5 of 6 years from 1981 to 1986), although in three of five years the sample sizes were small (11-20 measurements).

The overall length-frequency distribution for Herschel Island had a similar shape to that for the Komakuk area except that the whales near Herschel Island averaged 1 to 1.5 m larger (Fig. 15 vs. Fig. 18). Twenty-five percent of the measured whales from the Herschel Island area were adults, 44% were large subadults, 24% were small subadults and 7.9% were calves (Appendix 1). However, all 32 of the calves measured in the Herschel Island area were found in 1982, indicating that calf use of this area is overestimated because of the large number of photographs from the area in 1982 when calves were exceptionally abundant.

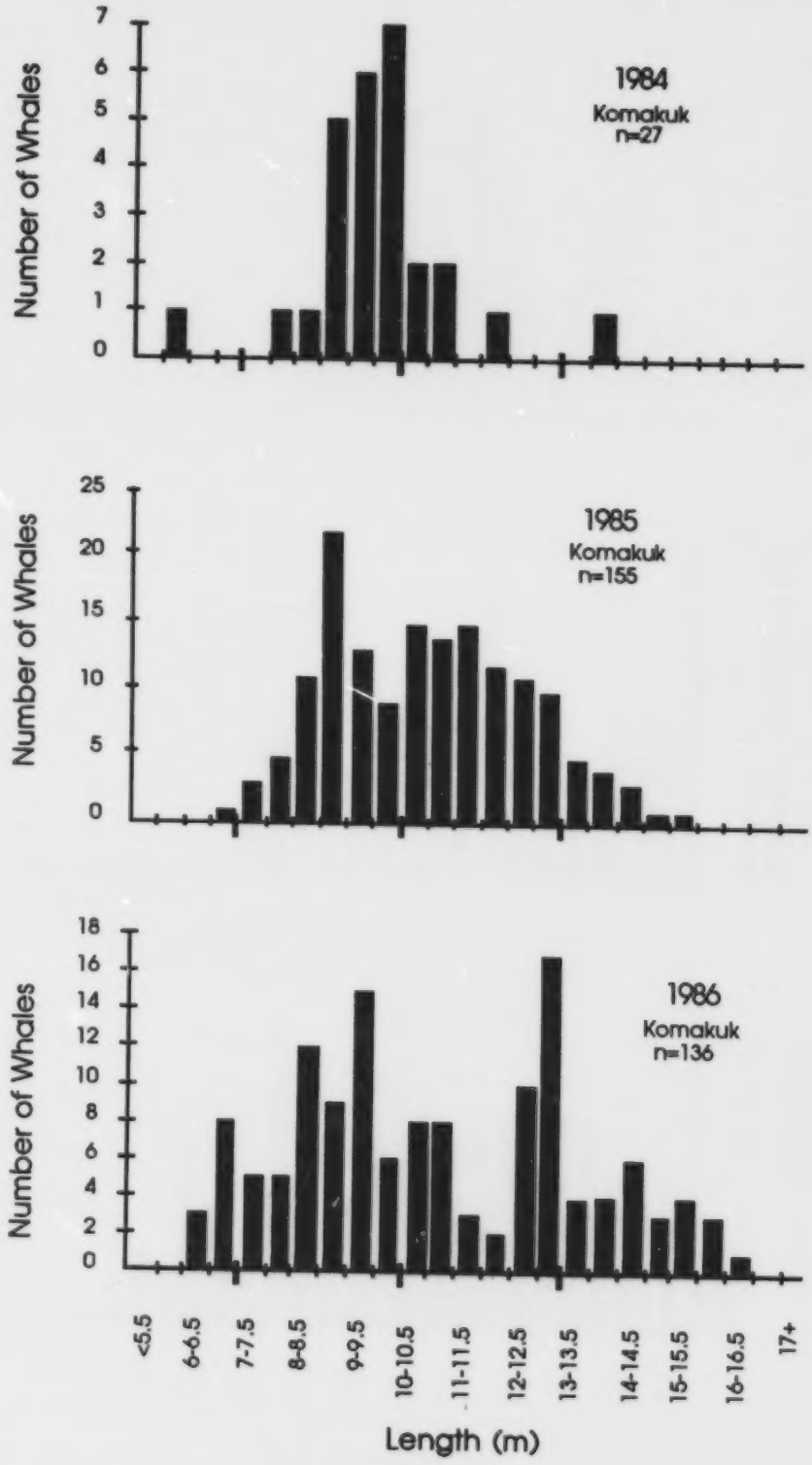


Figure 16. Length frequency distributions of bowhead whales photographed near Komakuk during 1984, 1985 and 1986.

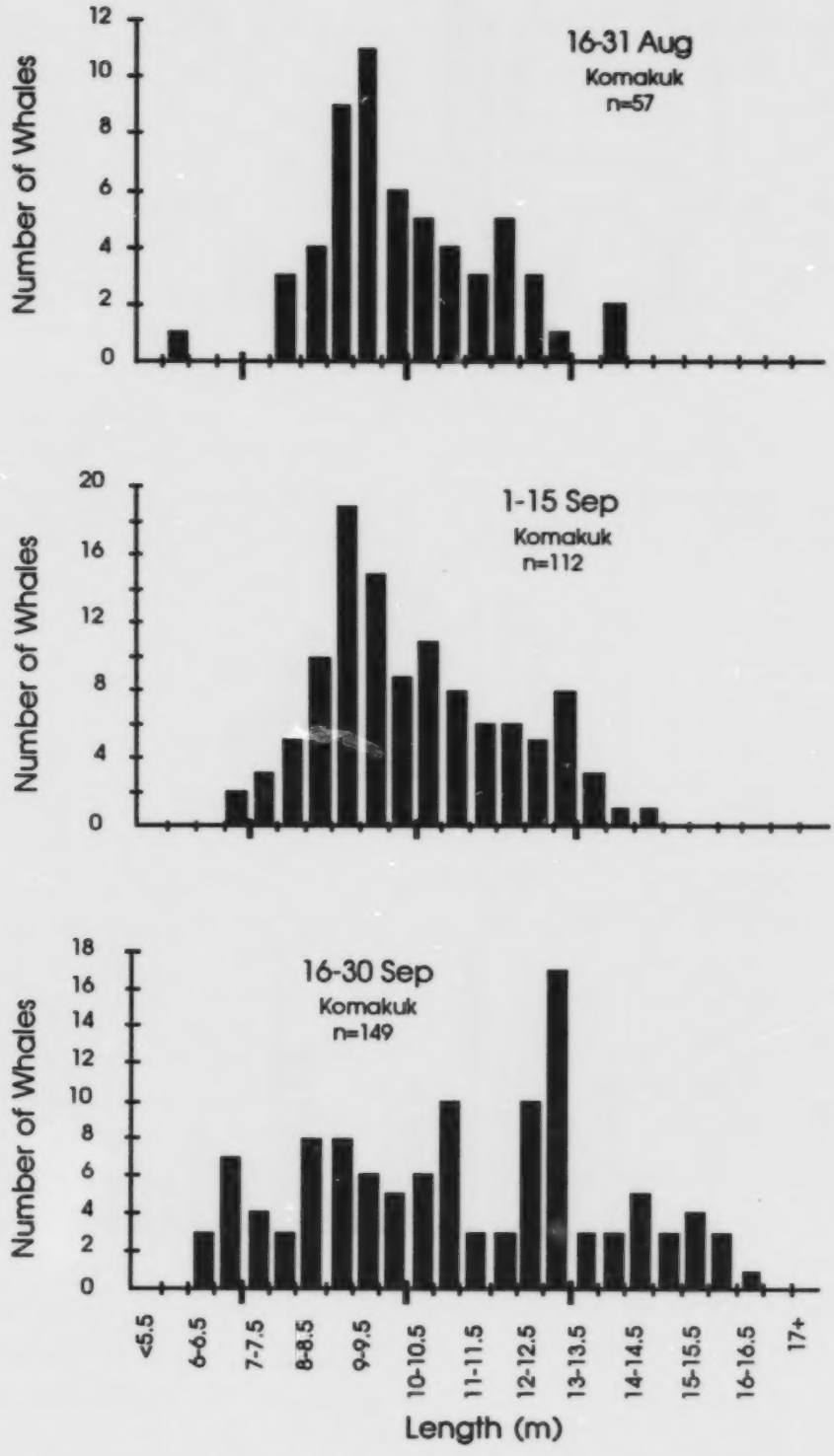


Figure 17. Length frequency distributions of bowhead whales photographed near Komakuk during late August, early September and late September.

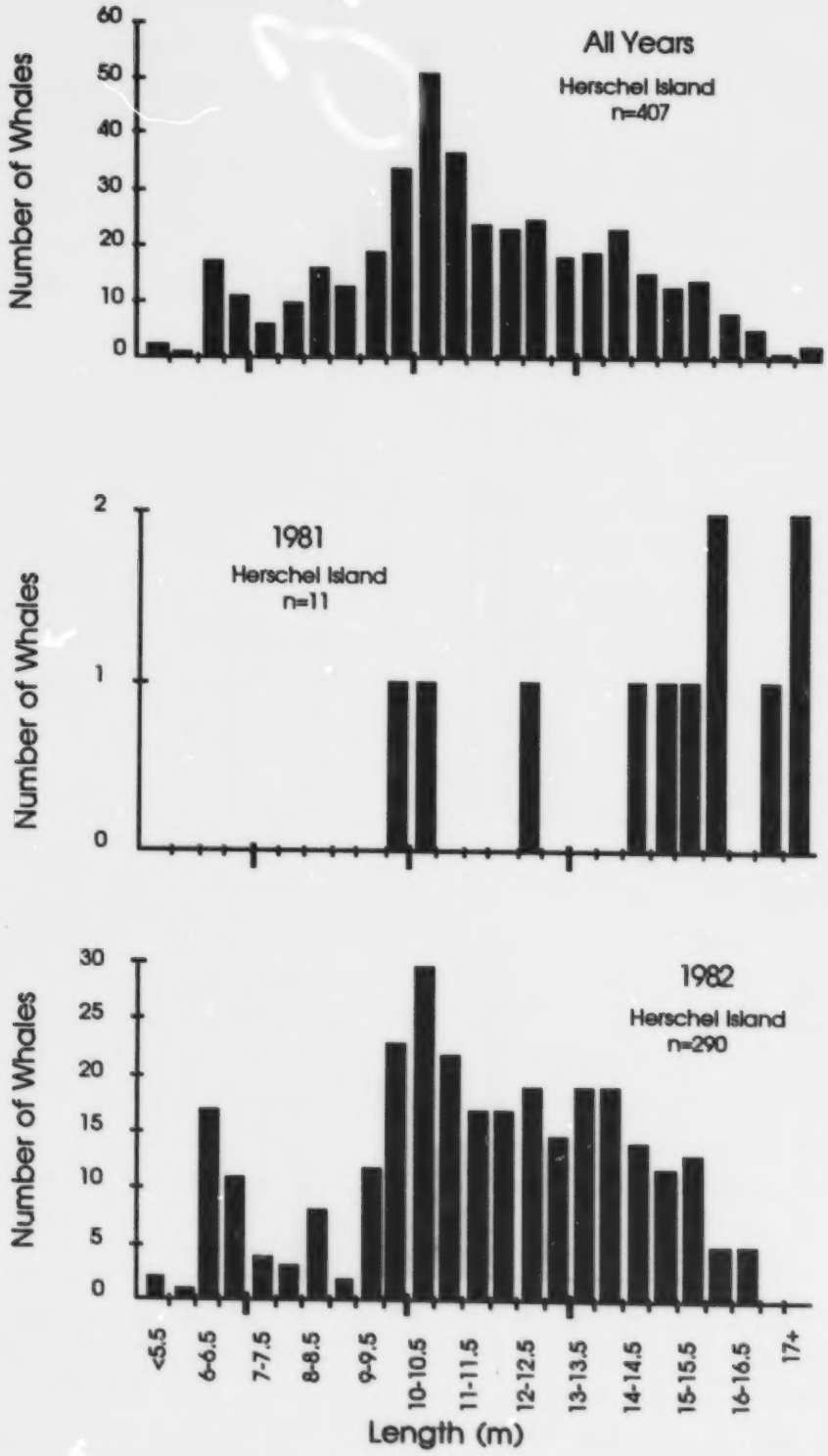


Figure 18. Length frequency distributions of bowhead whales photographed near Herschel Island and length frequency distribution of whales photographed each year 1981, 1982 and 1984-1986.

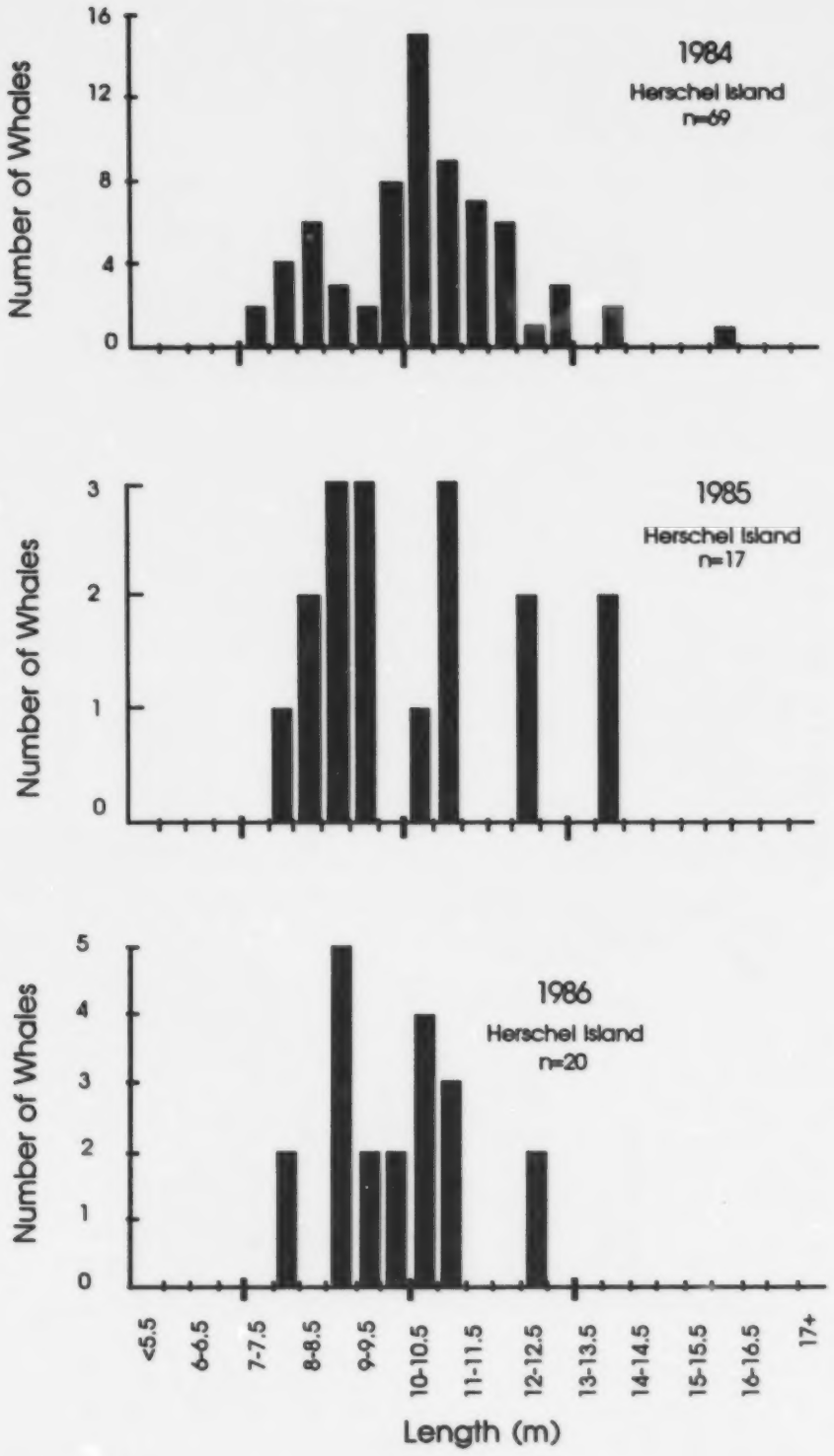


Figure 18. Con't.

The year-by-year length-frequency distributions vary considerably in the Herschel Island area (Fig. 18). In 1981, most (73%) of the few whales measured were adults and in 1982 30% were adults. However, in 1984-86 only 5% of the measured whales were adults. A potentially related factor was the local distribution of bowheads within the Herschel Island area. In 1982 most of the whales were in deep water,

The seasonal variation in whale sizes in the Herschel Island area was similar to that near Komakuk except that the larger whales moved into the Herschel Island area earlier (i.e. early September instead of late September). The late August size distribution was dominated by large subadults (46%) with smaller numbers of small subadults (26%) and adults (22%; Fig. 19). Calves made up 6.0% of the measured whales in late August. In early September, the proportions of the whales consisting of adults (29%) and calves (12.7%) had increased. Forty-four percent of adult whales photographed in this area in early September were accompanied by calves. Large and small subadults formed reduced percentages of measured whales, 39 of 19%, respectively, (Fig. 19).

King Point

Age segregation was more pronounced in the King Point area than in any other area (Fig. 20). Very large numbers of bowheads occurred in this area in late summer during 1983-86, although not in 1980-82 (Davis et al. 1986a,b; Richardson et al. 1987a). Only 1.6% of the whales photographed in this area were adults. Fifty-nine percent of the measured whales were smaller subadults and 38% were large subadults (Appendix 1). However, 65% of the 'large' subadults were 10-11 m in length, so 84% of all measured whales were non-calves smaller than 11 m (Fig. 20). This pattern occurred in all years (Fig. 21) and throughout the season from early August to early September (Fig. 22).

Interface

The whales in the Interface area consisted primarily of subadults. Only 4.3% of the measured whales were adults and 0.8% were calves. The subadults were almost equally divided into large (45%) and small (50%) subadults (Fig.

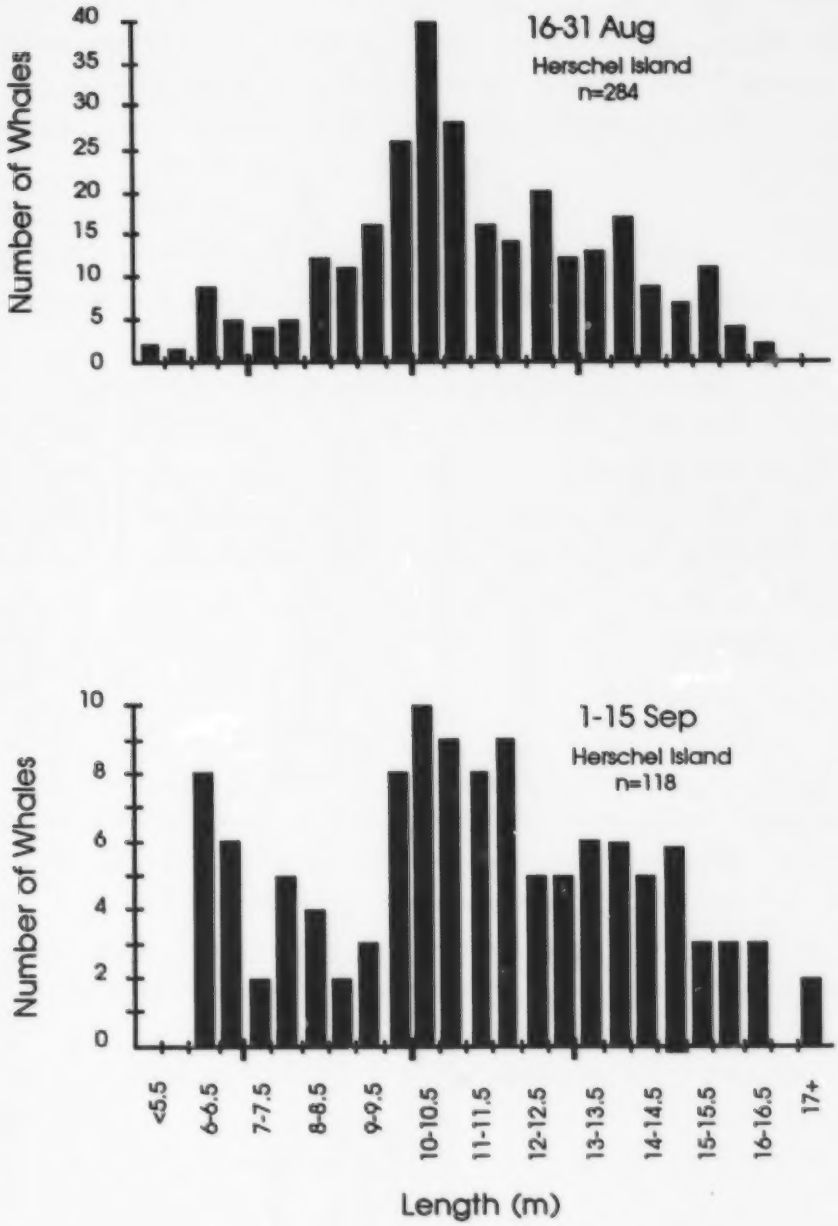


Figure 19. Length frequency distributions of bowhead whales photographed near Herschel Island in late August and early September.

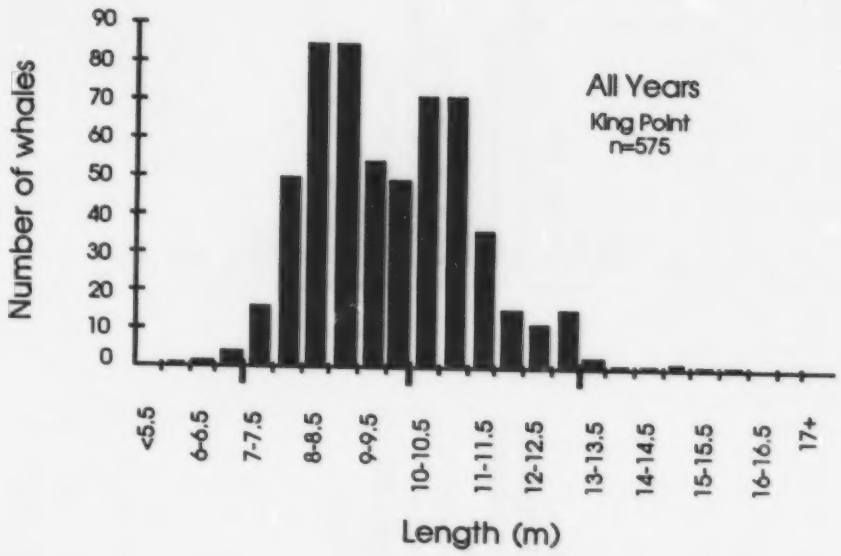


Figure 20. Length frequency distribution of bowhead whales photographed near King Point.

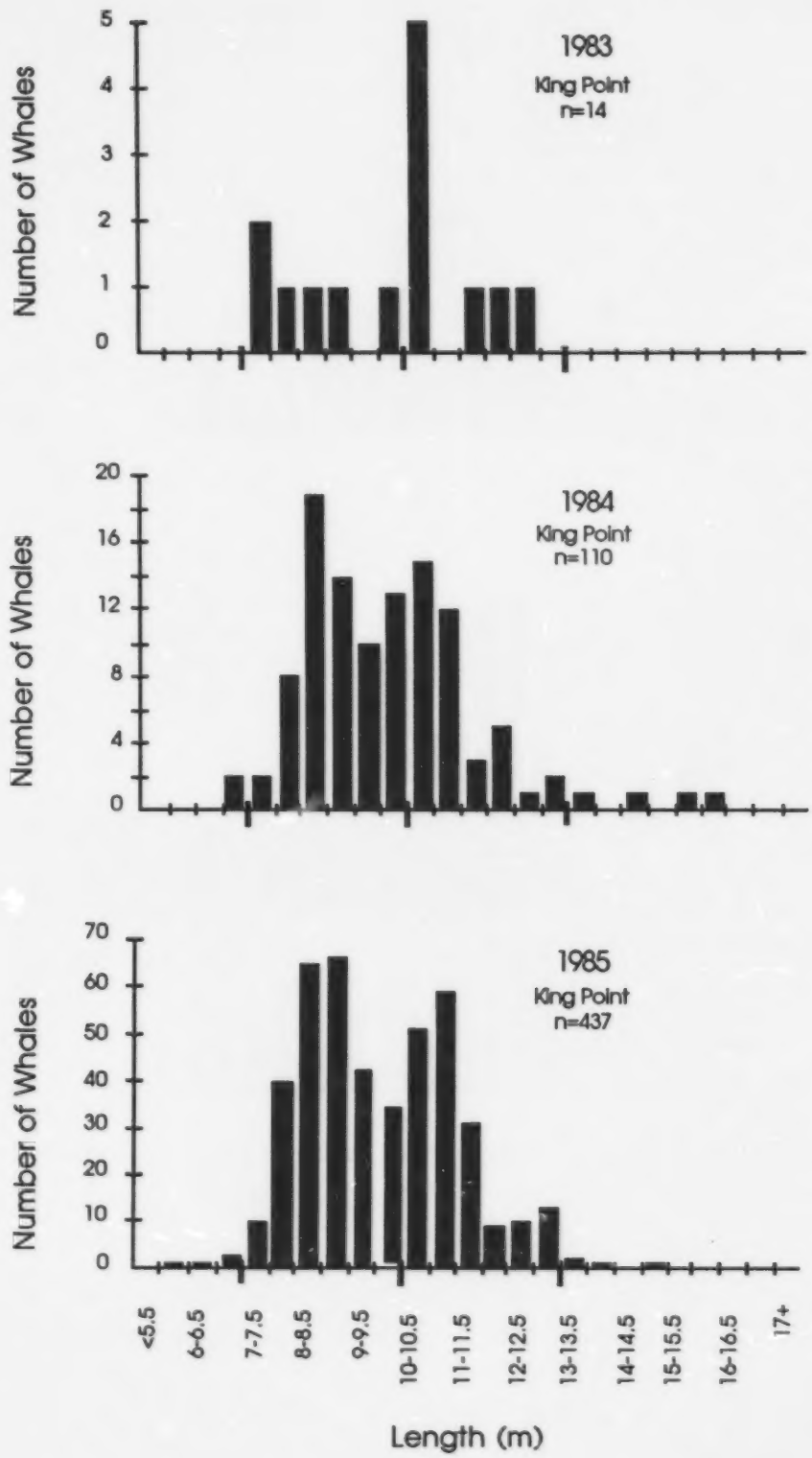


Figure 21. Length frequency distributions of bowhead whales photographed near King Point in 1983, 1984 and 1985.

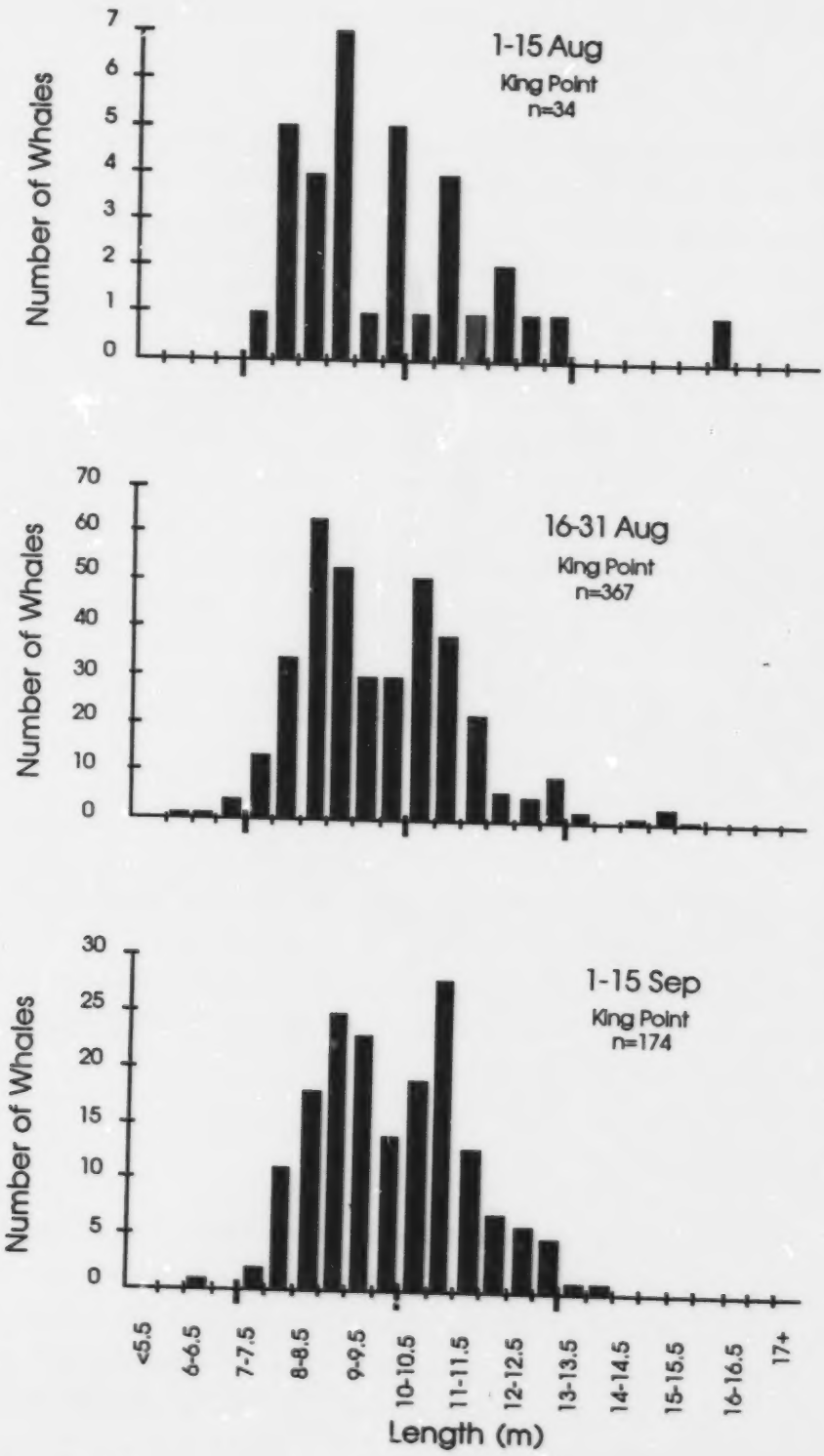


Figure 22. Length frequency distributions of bowhead whales photographed near King Point during early August, late August and early September.

23; Appendix 1). The Interface area had a slightly higher proportion of 9-11 m long subadults than did the King Point area.

Limited sample sizes for 1985-86 make detailed between-year comparisons in this zone of marginal value. However, in 1985 there was a high proportion of 7.5-9 m subadults, whereas in 1984 and 1986 the distribution consisted primarily of animals longer than 9 m (Fig. 24).

Delta Shelfbreak

No small subadult bowheads were photographed in the Delta Shelfbreak area (Fig. 25). Fifty-three percent of the measurements were of adults, 30% were large subadults and 16% were calves (Appendix 1). Thirty percent of the adults photographed in this area were accompanied by calves. The relative importance of this area to calves may be overstated by the data because all measurements for this area came from 1982--the year when unusually large numbers of calves were present and photographed. Whales were not found in this area in the intensive studies in 1985.

Industrial Area

Similar to the Delta Shelfbreak, most of the whales measured from the Industrial Area were either adults (55%) or large subadults (36%). Unlike the Delta Shelfbreak area, a few small subadults (9%) and no calves were recorded. The small sample from this area is in spite of substantial searches in the area in 1982, 1984, 1985 and 1986.

Tuktoyaktuk Peninsula Shelf

The length-frequency distribution of the whales from the Tuktoyaktuk Peninsula Shelf (Tuk Pen Shelf) is not strongly dominated by any one length class (Fig. 26) as were most of the previous areas. Twenty-seven percent of the measured whales were adults, 40% were large subadults, 27% were small subadults and 5.4% were calves. Twenty percent of the adults measured from this area were associated with calves.

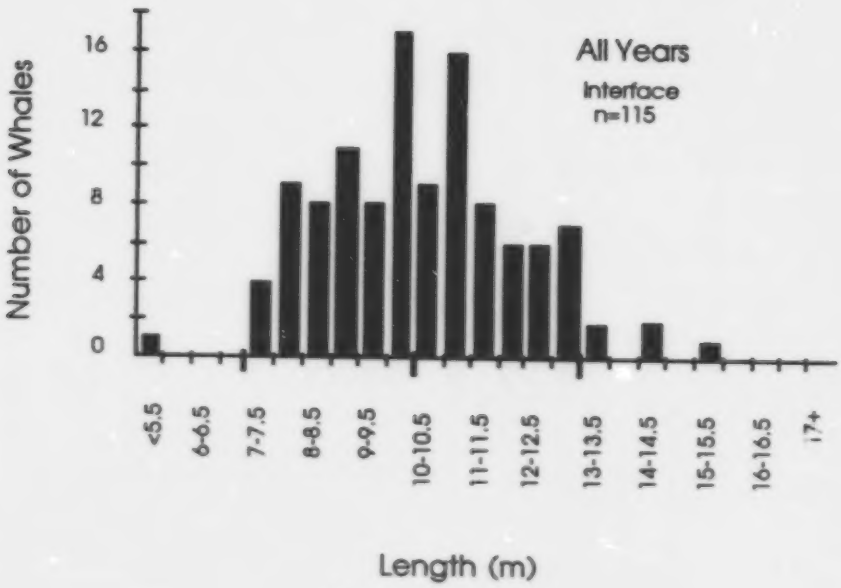


Figure 23. Length frequency distribution of all bowhead whales photographed in the Interface area.

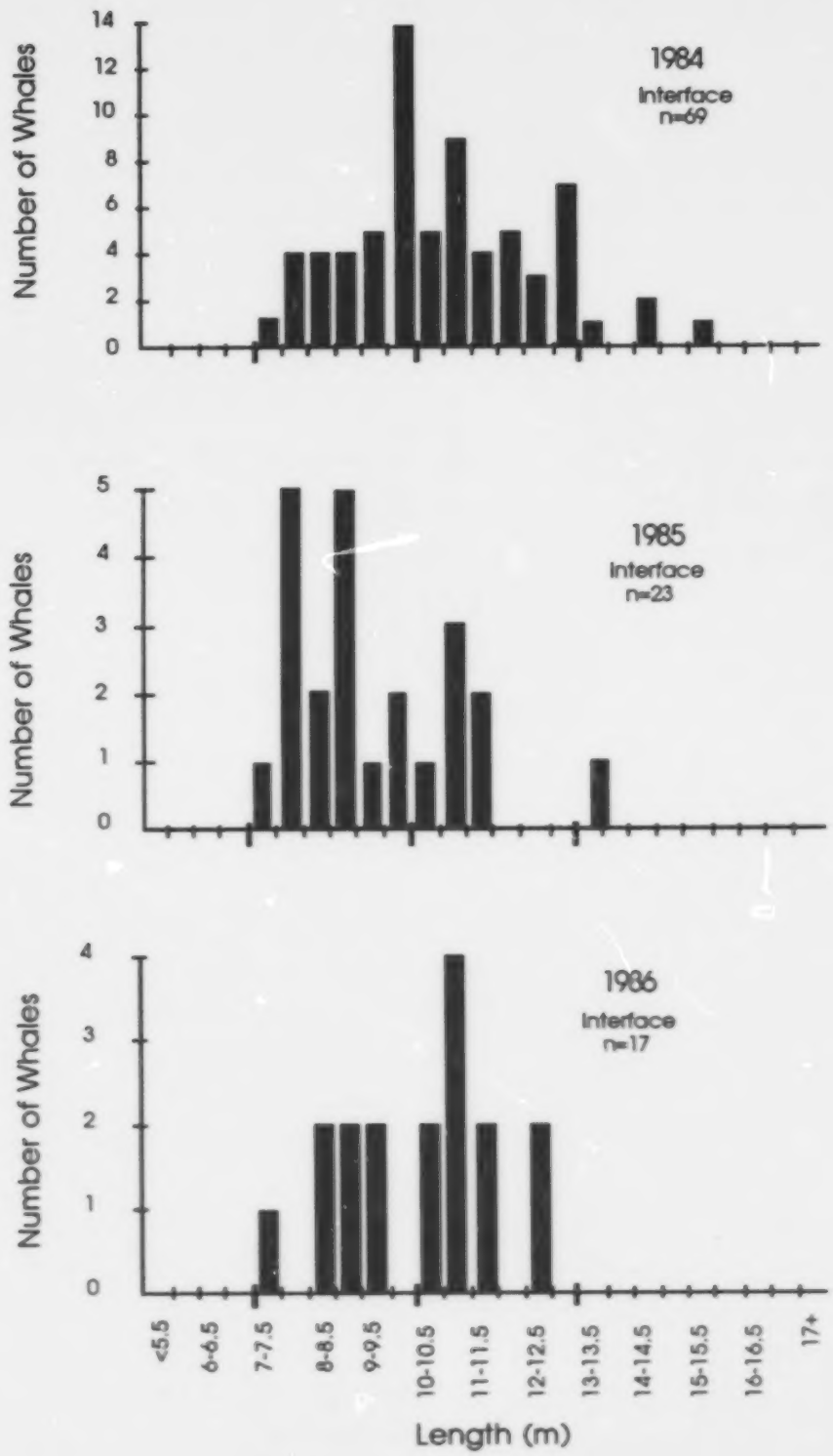
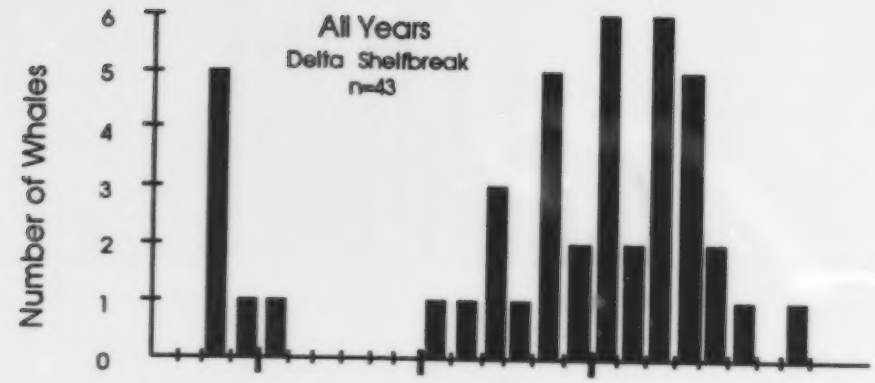


Figure 24. Length frequency distributions of bowhead whales photographed in the Interface area, 1984-1986.



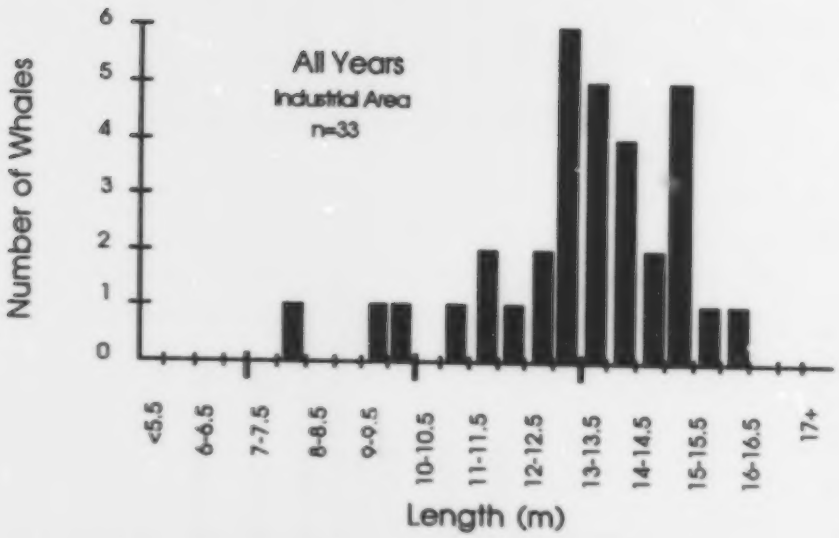


Figure 25. Length frequency distributions of all bowhead whales photographed in the Delta Shelfbreak and Industrial areas.

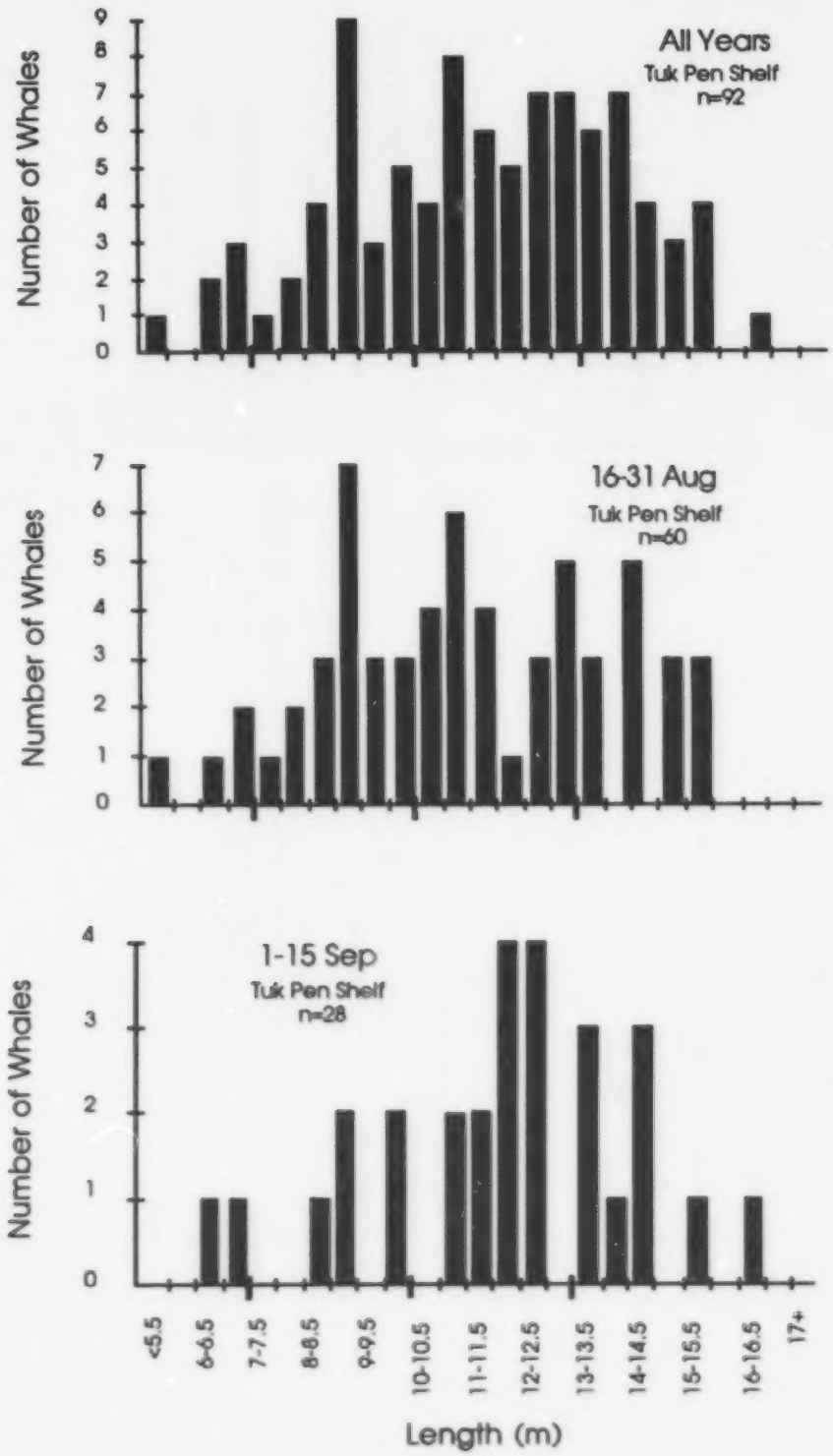


Figure 26. Length frequency distributions of all bowhead whales photographed on the Tuk Pen Shelf and of bowheads photographed there in late August and early September.

The length-frequency distribution changed slightly from late August to early September (Fig. 26) as the small subadults moved westward to the Interface, King Point and Komakuk areas and large subadults and adults moved in from Amundsen Gulf.

Offshore Bathurst Peninsula

Few whales (21) have been measured from the Cape Bathurst area, although whales are common there, at times. The measured whales from this area were primarily adults (48%) and large subadults (48%; Fig. 27; Appendix 1). No calves were photographed in this area.

Franklin Bay

The length-frequency distribution of whales from Franklin Bay was heavily weighted towards adults (54%) and large subadults (32%; Fig. 28; Appendix 1). Despite the large number of adults measured (85) only two calves (1.3% of all whales) were measured. It is worth noting that most of the large subadults were 12-13. m.

A few small whales were present in the very small sample of measured whales from early August (Fig. 29). By mid August the large numbers of adults and large subadults were present. The few adults with calves were recorded in early September and by mid September most bowheads had moved westward out of Amundsen Gulf.

Cape Parry

The length-frequency distribution of the small sample (33) of whales from the Cape Parry area was similar to that of Franklin Bay (Figs. 28 and 30). Few studies have photographed whales east of Franklin Bay so there are fewer data for Cape Parry and areas north and east than for Franklin Bay and nearshore areas to the west.

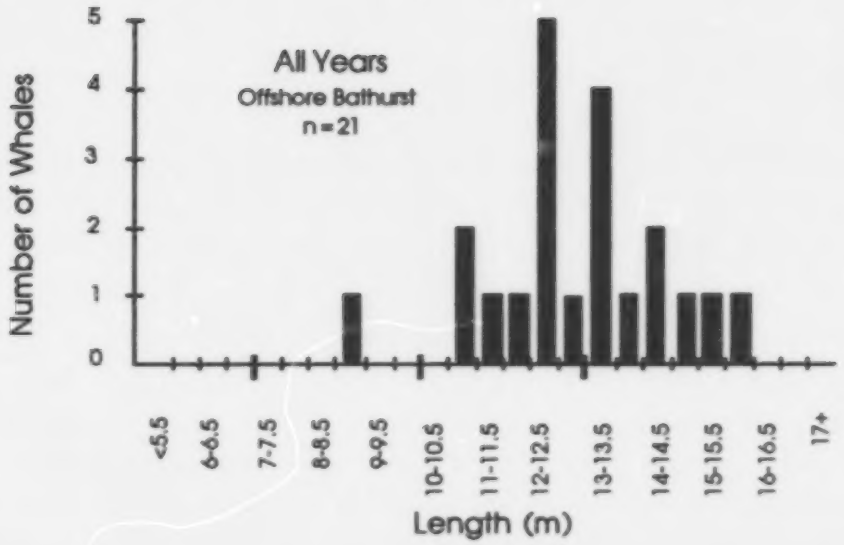


Figure 27. Length frequency distribution of all bowhead whales photographed in the Offshore Bathurst Zone.

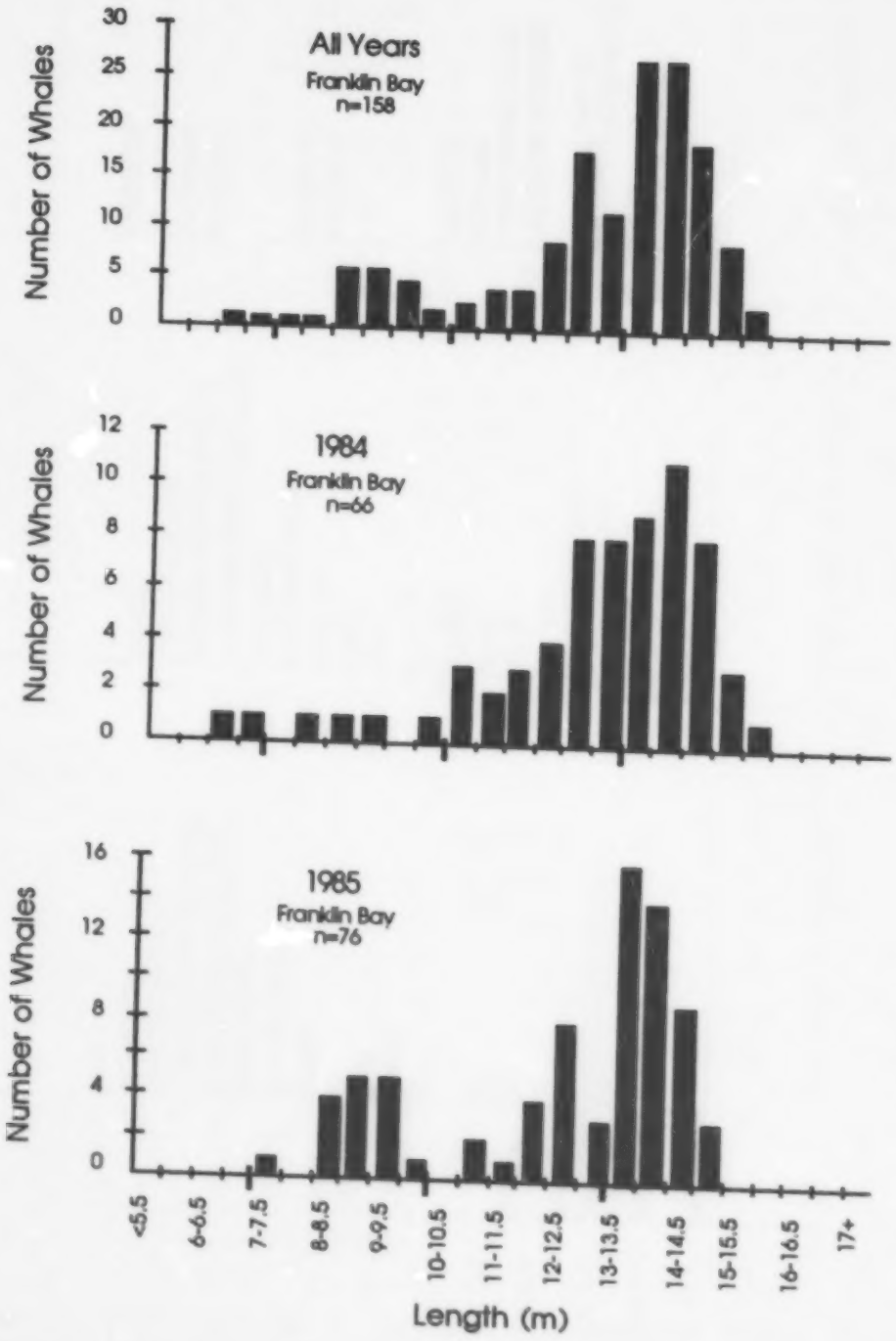


Figure 28. Length frequency distributions of all bowhead whales photographed in Franklin Bay and those photographed during 1984 and 1985 in Franklin Bay.

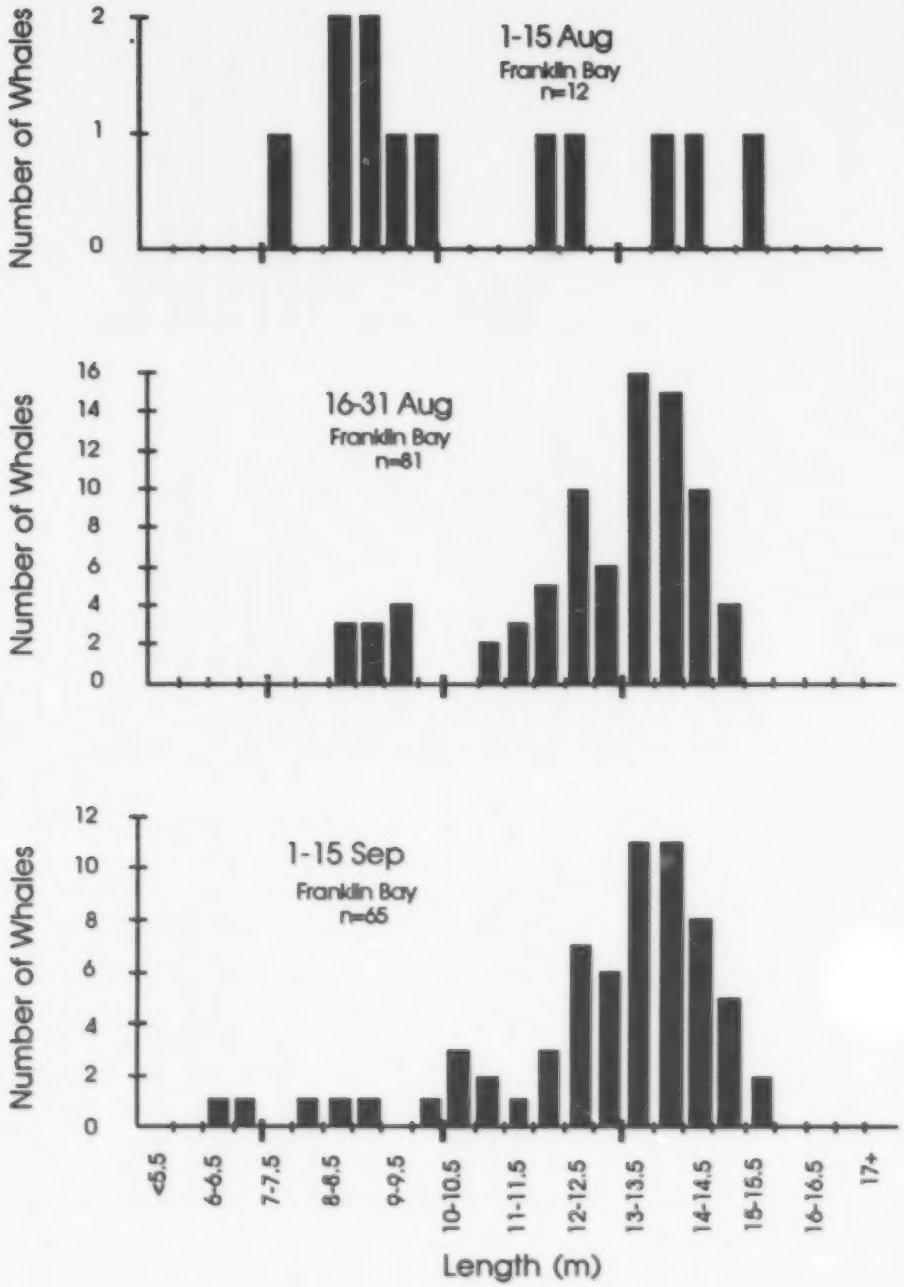


Figure 29. Length frequency distributions of bowhead whales photographed in Franklin Bay in early August, late August and early September.

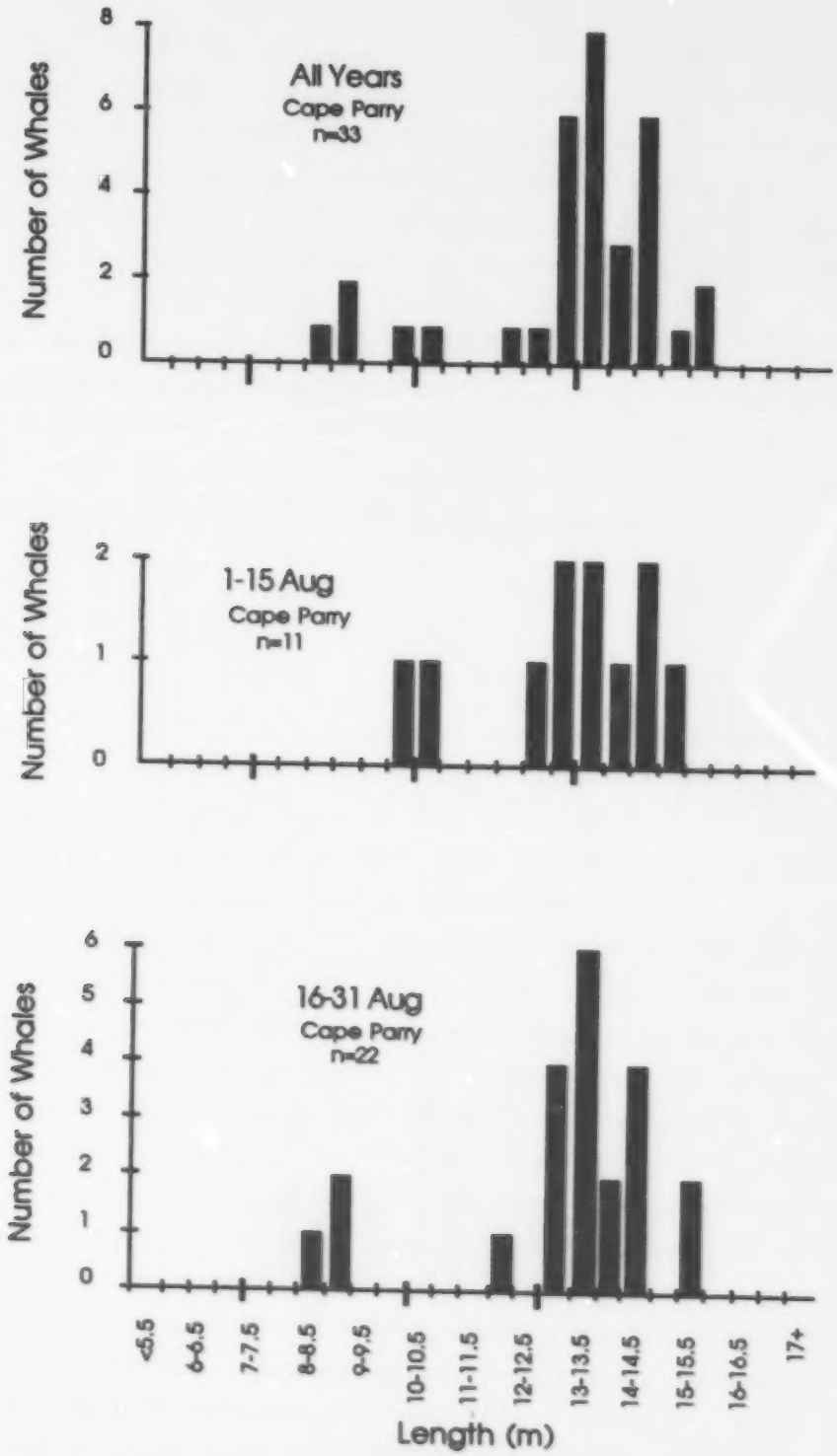


Figure 30. Length frequency distribution of all bowhead whales photographed in the Cape Parry area and of those photographed there in early and late August.

North Central Amundsen

The length-frequency distribution for NC Amundsen Gulf was similar to Franklin Bay and Cape Parry except that the whales were on average larger (Figs. 28, 30 and 31). Sixty-eight percent of the whales measured from this area were adults; this is the highest proportion of adults among all areas discussed. However, only one calf (1.7%) was measured.

The length-frequency distributions were considerably different during the two years when photographs were obtained in NC Amundsen Gulf. During 1981, 91% of the whales were adults, whereas during 1985 only 38% were adults. Whales have arrived in Amundsen Gulf by mid-to-late July, but no length information is available from this period. All of the lengths in Figure 31 are from the 1-15 August period.

Summary

Year-to-year changes in whale distribution and timing of movements have been documented; some of these changes probably are related to ice conditions and availability of food. However, despite these changes, there are patterns of whale usage of different areas that seem to be repeated during most years. In early to mid August of many years subadult bowheads move into nearshore areas, probably largely from the offshore pack ice, and larger subadults and adults move shoreward (but not necessarily into nearshore areas) close behind. Length data suggest that most cows with calves often remain offshore or elsewhere outside the area where whales have been studied until late in the season. Larger whales tend to be found farther east or in deeper water than smaller whales. Different size classes of whales appear to traditionally use the same area. For example, very small subadults tend to be found in greatest numbers along the Yukon Coast from Shingle Point to Kay Point (our King Point area). The many subadults close to shore near Komakuk in certain years tend to be slightly larger, although with much overlap. The Interface and the Herschel Island areas support large numbers of medium-sized subadults. Whales in the shelfbreak areas and Amundsen Gulf consist primarily of large subadults and adults. However, relatively few calves have been found in Amundsen Gulf

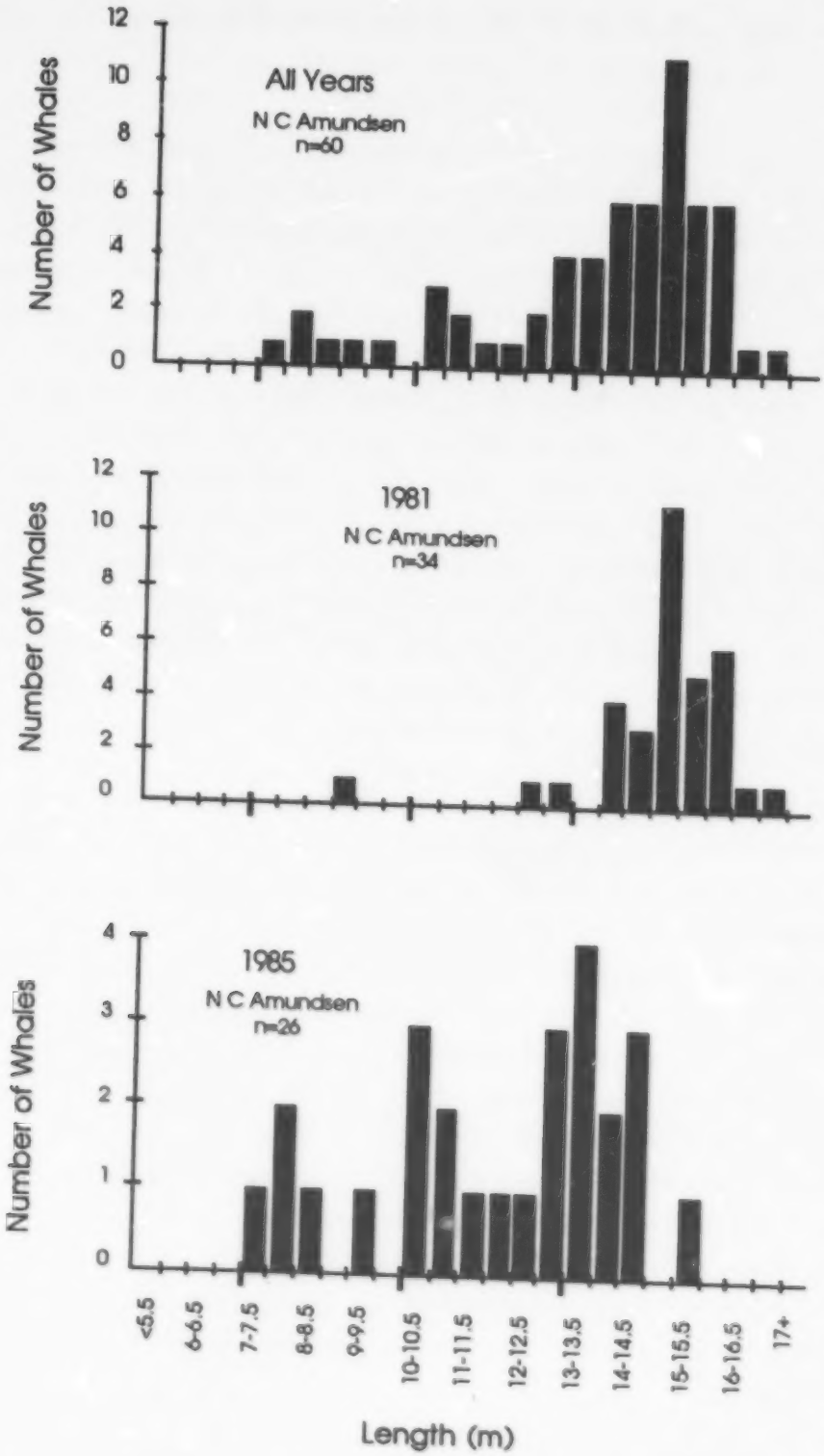


Figure 31. Length frequency distributions of all bowheads photographed in NC Amundsen Gulf and of those photographed during 1981 and 1985 in NC Amundsen Gulf.

despite the high proportion of adults there. The Tuktoyaktuk Peninsula Shelf seems to contain a cross-section of all size classes.

In most years these areas do not account for all of the Western Arctic bowhead population. In 1982, the small subadult portion of the population did not come into the King Point area and its whereabouts was not determined (cf. Fig. 10). During 1984 and 1985 only a small segment of the adult segment of the population could be accounted for (Davis et al. 1986a,b). In fact, during most years a major portion of the adult and possibly subadult population cannot be accounted for (Davis et al. 1986b), particularly if the current IWC estimate (about 7800 bowheads, IWC in press) is even close to the actual population size. Assuming that almost all of these whales enter the Beaufort Sea each year, they must be scattered offshore among the pack ice. Unfortunately, this offshore area is too large to survey and to photograph the whales economically. In some years, such as 1980, much if not all of the bowhead population moves into nearshore areas. A photogrammetry study during such a year would provide the information on the missing age classes.

3. EFFECTS OF AGE ON BOWHEAD BEHAVIOR

Introduction

The previous section clearly shows that bowheads of various age classes are not uniformly distributed throughout the summering grounds. Thus, any study of the potential effects of tanker traffic must determine which age classes are likely to be exposed to ship noise. It would be helpful to determine whether all age classes respond to ships in the same way. Do the large numbers of small, subadult animals that summer along the Yukon coast react in the same way as adults or adults with calves? We attempted to quantify age-related behavior patterns by examining available quantitative data on bowhead behavior collected during studies that LGL conducted for the U.S. Minerals Management Service during the 1980-86 period. Unfortunately, because of the biased age distributions and because of other study priorities, it has not been possible to directly assess the question.

Available Data

The normal, undisturbed behavior of bowheads in the Canadian Beaufort Sea was documented during a five year study by Würsig et al. (1985). Further behavioral observations were made in 1985-86 in the eastern Alaskan and western Canadian Beaufort Sea (Richardson et al. 1987b). During those studies, quantitative data on respiration, surfacing and dive characteristics were collected. Four characteristics of surfacing lend themselves to repeated quantitative sampling: the interval between blows in a surfacing (blow interval), the number of blows per surfacing, the duration of surfacing (surface time), and the duration of dives between surfacings (dive time). Because these variables are comparatively easy to assess quantitatively, they are suitable for use in analysis of responses to disturbances. A detailed understanding of respiration, surfacing and dive behavior under undisturbed conditions is a prerequisite for interpretation of disturbance responses. A detailed documentation of undisturbed bowhead behavior is given by Würsig et al. (1985).

During some behavior observation sessions from 1982 onward, aerial photographs were also taken and these provide information on the lengths (= age) of the animals. In other cases, concurrent studies by other investigators photographed the whales studied by behaviorists. These data increased the samples of measured whales for which behavior was studied. Unfortunately, for present purposes, the great majority of these whales were subadult, non-breeding animals that occurred in shallow, shelf waters. Few behavioral sessions were conducted over deeper waters where large adults occur and even fewer of these sessions were combined with photographic coverage and absence of potential industrial disturbance. Thus, sample sizes were too small to quantify the normal and undisturbed behavior of adult animals after taking account of all of the various relevant environmental conditions, such as water depth. In gray and humpback whales, depth of dive is known to be positively correlated with durations of dives and surfacings, and number of respirations per surfacing (Würsig et al. 1986; Dolphin 1987a,b).

Results

1980-84

In the absence of sufficient information on behavior of known adult animals, we refer the reader to the following analyses by Würsig et al. (1985) that examine the effects of water depth on whale behavior. Data on 2129 surfacings and 475 dives were available from undisturbed conditions. It is reasonable to expect that diving behavior of feeding whales would vary with water depth (e.g., longer dives in deeper water). It is also known that adult animals tend to occur in deeper water than do the smaller subadults.

In the 1980-84 study, blow intervals did not show any consistent trend with increasing water depth (Fig. 32). Although there were statistically significant differences between means for various depth categories, these differences probably were due to factors other than water depth. The other three variables--number of blows per surfacing, surface time, and dive time--all showed more or less clear tendencies to increase with increasing depth.

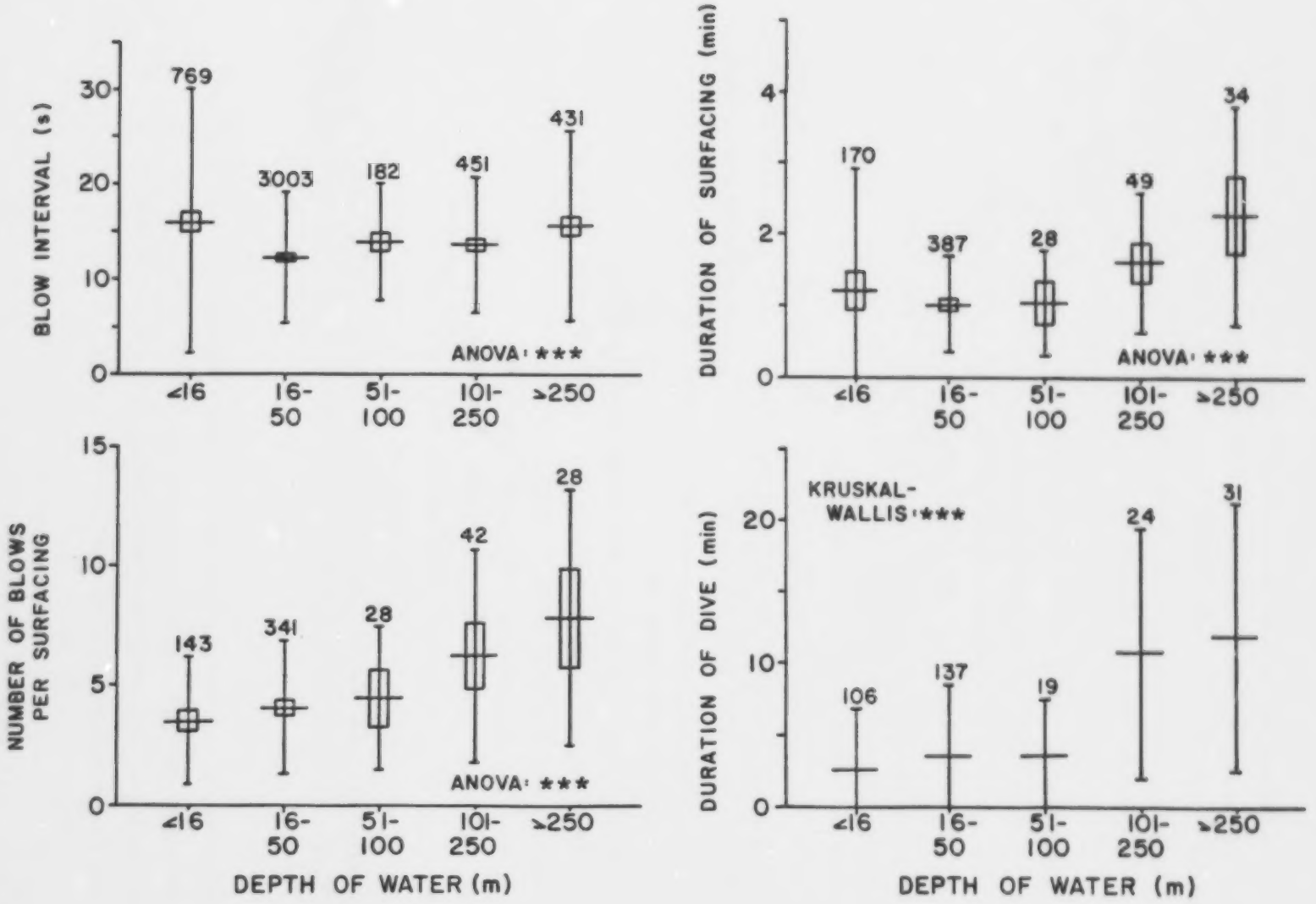


Figure 32. Comparison of respiration, surfacing and dive characteristics for bowheads in five categories of water depth, 1980-84. Only presumably undisturbed non-calves are included. *** means $p \leq 0.001$. (from Würsig et al. 1985).

Number of blows per surfacing showed the increasing trend most clearly (Fig. 32). The means for the shallowest three categories (<100 m) were not significantly different from each other, but the means for each of the two deepest categories were significantly different from the means for each of the three shallower depths ($p<0.05$ in each case, Newman-Keuls tests).

For duration of surfacing, as for number of blows per surfacing, the means for the three shallowest depth categories did not differ significantly. The mean for the deepest category (>250 m) was significantly higher than any of the other means ($p<0.001$ in each case, Newman-Keuls tests). The mean for 101-250 m was significantly higher than the means for <16 m and for 16-50 m ($p<0.025$ in each case).

For duration of dive, means for the two deepest categories were significantly greater than means for the three shallowest categories (Dunn's multiple comparisons, $p<0.05$ in each case). Means for the two deepest categories were similar, as were means for the three shallowest categories.

In general, number of blows per surfacing, duration of surfacing and duration of dive tended to be greater in deep (>100 m) water than in shallow (<100 m) water. These trends were largely attributable to the high values of these variables in 1982, a year when most observations were in deep water. There was only very limited evidence that the trends existed within single years. Thus, it is difficult to determine whether the trends were attributable to depth or year effects. In 1982, many of the behavior sessions involved adult animals in deep water. Thus, the differential behavior in 1982 may reflect water depth or the presence of adult whales or a combination of both factors.

Würsig et al. (1985) performed multiple regression analyses on four years' behavior data to try to sort out intercorrelated factors and true causative factors. The analyses demonstrated the complexity of the problem, but failed to clearly separate age, year and water depth effects.

1985-86

Behavioral observations of bowheads near the Alaska/Yukon border in September 1985 and 1986 were reported by Richardson et al. (1987b). They used the same techniques as Würsig et al. (1985). They documented 2031 blow intervals, 123 'blows per surfacing' events, 192 durations of surfacing, and 60 dive durations. The means, ranges and distributions of these four variables were generally similar to those observed in previous studies. Depths of water at locations where whales were observed systematically during September 1985-86 almost always were 5-50 m. The one exception involved whales in water 280 m deep on 22 September 1985, when there was moderately strong seismic noise. The overall results from September 1985-86 showed that mean blow interval, number of blows per surfacing, duration of surfacing, and duration of dive were all positively correlated with water depth (Table 3). The same trends were evident for presumably undisturbed whales, potentially disturbed whales, and all whales.

Table 3. Correlations between water depth and the various surfacing, respiration and dive variables, September 1985-86 (from Richardson et al. 1987b).

	Spearman Rank Correlation	n	p[b]
Mean Blow Interval[a] vs. Depth			
Presum. Undisturbed	0.225	330	***
Potent. Disturbed	0.263	137	**
All	0.280	467	***
# Blows/Surfacing vs. Depth			
Presum. Undisturbed	0.441	68	***
Potent. Disturbed	0.674	55	***
All	0.484	123	***
Duration of Surfacing vs. Depth			
Presum. Undisturbed	0.436	114	***
Potent. Disturbed	0.595	78	***
All	0.458	192	***
Duration of Dive vs. Depth			
Presum. Undisturbed	0.539	28	**
Potent. Disturbed	0.642	32	***
All	0.575	60	***

[a] Mean of all blow intervals within a given surfacing.
[b] ** means $0.01 \geq p > 0.001$, and *** means $p \leq 0.001$.

Most of the whales observed in shallow water during the 1985-86 study were subadults (mainly small subadults), whereas those in deeper water consisted of a mix of subadults (mainly large) plus adults. Thus, the observed differences in behavior as a function of water depth may represent depth effects, age or size effects, or some combination.

Previous observations in Alaska during autumn have also demonstrated that mean duration of surfacing and mean number of blows per surfacing tend to increase with increasing water depth (Ljungblad et al. 1984b, 1985b). Previous autumn data for presumably undisturbed whales (Ljungblad et al. 1985b) also indicate that mean duration of dives increases with increasing water depth. No clear correlation between blow intervals and water depth had been demonstrated in this previous work, and there was no information about the sizes of the whales that were observed in the study by Ljungblad et al.

Conclusions

The results of all studies are consistent in demonstrating that bowhead behavior changes as water depth increases. Mean durations of surfacings, number of blows per surfacing, and durations of dives are all greater for whales observed in deeper water. This finding must be taken into account during any study that assesses the effects of tankers on whale behavior. Such studies will need to have both experimental and control units in each of shallow and deep waters. If large amounts of deep water are to be traversed, further baseline studies of normal behavior would be needed to determine whether normal behavior changes further when whales are in very deep water, where very few behavioral data have been collected.

The original question regarding whether quantitative aspects of behavior vary with whale age cannot be answered with available data. All that can be said is that the behavior of whales in deeper waters is statistically different than for whales in shallower waters and older whales tend to occur in deeper waters.

4. PHOTO IDENTIFICATION FILE AND DATA BASE

Photograph Library

We obtained photographs for photo-identification analyses from four different studies aside from our own (Table 4). We were provided collections of printed whale images from the 1983 Cascadia Research Collective and 1984 National Marine Fisheries Service (NMFS) studies. We produced our own set of custom prints (5" x 7") from the original photographic transparencies and negatives obtained in the 1985 and 1986 Cascadia studies. The numbers of printed bowhead images and printed individual bowheads (recognized repeat photographs excluded) are shown in Table 4.

Table 4. New photographs used in photo-identification analyses conducted for the present study.

Source of Photographs		No. of Printed Bowhead Images				No. of Printed Individuals			
		Re-identification Grade[b]				Re-identification Grade[b]			
Year	Agency[a]	A	B	C	Total	A	B	C	Total
1983	CRC	29	60	42	131	27	59	41	127
1984	NMFS	12	20	0	32	12	19	0	31
1985	CRC	25	51	7	83	17	37	6	60
1986	CRC	92	150	1	243	67	122	1	190
Totals		158	281	50	489	123	237	48	408

[a] NMFS = U.S. National Marine Fisheries Service, Seattle, WA; CRC = Cascadia Research Collective, Olympia, WA.
[b] See below for definition of Re-identification Grades.

The collection of prints at LGL's King City office constitutes the only complete set of vertical photographs of summering bowheads. Some but not all of the photographs taken by NMFS at Barrow during spring also are in the LGL collection. The numbers of bowhead whale images taken over the years and archived in the LGL collection are summarized in Table 5. There are now 1422 images of whales that are potentially identifiable if photographed in another year (i.e. Grade A, see below).

Table 5. Summary of studies of bowheads that have used aerial photogrammetric techniques.

Year	Agency[a]	Purpose of Study	No. of Images Identifiable: Within Year (Grades A + B)	No. of Images Identifiable: Between Years (Grade A)	Report of Study
1981	LGL	Popul. Estimate	76	37*	Davis et al. (1982)
1982	LGL	Life History	502	279	Davis et al. (1983)
1983	CRC	Life History	86*	27*	Cubbage et al. (1984)
	LGL	Behavior	20	1	Richardson (ed.) (1985)
1984	LGL	Disturbance	942	231	Davis et al. (1986a)
	NMFS	Life History	31*	12*	Unpublished summer data
	NMFS	Spring Migration	6	?	-
1985	NMFS	Spring Migration	493	?	I.W.C. Working Paper
	LGL	Reprod. Rate	1161	467	Davis et al. (1986b)
	CRC	Distribution	54*	17*	Cubbage and Calambokidis (1987a)
	LGL	Feeding	212	119	Richardson et al. (1987b)
	LGL	Disturbance	21	5	Johnson et al. (1986)
1986	NMFS	Spring Migration	256	?	I.W.C. Working Paper
	CRC	Distribution	189*	67*	Ford et al. (1987)
	LGL	Feeding	291	105	Richardson et al. (1987b)
	LGL	Disturbance	151	55	Koski and Johnson (1987)
1987	NMFS	Spring Migration	200+	?	-
		Approx. Totals	4,691+	1,422++	

[a] LGL = LGL Limited; NMFS = U.S. National Marine Fisheries Service; CRC = Cascadia Research Collective, Washington.

* Asterisk indicates number of different whales, not the number of images.

Re-Identification Grades and Files

Each image newly-obtained for this study was assigned a re-identification grade in the same manner as previous studies and placed in one of 20 files based on the amount of white on the lower jaw and tail regions (Davis et al. 1983, 1986a,b; Richardson et al. 1987b; Koski and Johnson 1987). Photographs of whales that we believe would be recognizable in a photograph of similar or better quality taken in another year were given a grade of A. Photographs of whales that would be recognizable in a photograph of similar or better quality taken the same day or within a few days of the date of the original photograph were given a grade of B. Photographs of whales that we considered would not be recognizable in a photograph of similar or better quality taken on the same or any other day were given a grade of C. The grading of prints involves a number of subjective assessments of the quality of the photograph (including consideration of focus, resolution, lighting, glare, reflection, sea state, water turbidity, and the position of the whale) and the distinctiveness of the markings on the whale. A poor quality photograph of a very distinctively marked whale might be graded A while an excellent photograph of a whale with no distinctive markings might be graded C. Whales given a grade of B are often well marked with features such as mottled patterns (molting) that we believe to be temporary.

We compared all grade A and B photographs taken in each CRC and NMFS study (1983, 1984, 1985 and 1986) with one another to determine which images were within or between-day resightings. We then compared all newly-obtained grade A photographs with each grade A photograph within the same file or within files having similar characteristics. More than half of the between study duplicates found were identified as definite or potential matches while selecting and labeling slides and prints prior to systematic comparisons of photographs.

Photographic Data Base

Previous to this study, LGL developed a computerized data base that contained the data concerning photographs obtained during LGL studies. The data base was complete for studies conducted in 1985 and 1986, but contained

only basic recorded information for photographs collected during 1981-1984. As the first phase of this study, the data base was expanded to include NMFS and CRC photographs from the summers of 1983-86. In addition, missing data for LGL's 1981-84 photos were incorporated into the database. The computerized database now contains full documentation for all bowhead photos obtained in the Beaufort Sea during summer and autumn and archived at LGL.

The database is a data file with fixed format. Each whale image in the file is identified by an image number assigned by the agency that obtained the photograph and a whale number, which is constant for all photographs of an individual whale. Information recorded for each image includes date, time, location (latitude and longitude), water depth, distance from shore and ice cover. For each whale we recorded its length; reidentification grade and file; and whether it was rephotographed on the same day, different days or different years.

5. MICRO-SCALE MOVEMENTS

Any further studies of the effects of tanker traffic on bowhead whales must be based on an understanding of normal movement patterns in the absence of disturbance sources. Do individual bowheads tend to stay in the same area for periods of several hours or do they frequently move? Without knowing the answer to this question, it will be difficult in future studies to determine whether observed movement patterns are due to tanker traffic or whether they represent normal movements, perhaps in response to drifting food sources. We examine these micro-scale movement patterns in this section using data from whales rephotographed on the same day.

Methods

During aerial photography studies of bowheads, the aircraft typically circles over a group of whales taking photographs until it is decided to move to another group of whales in another area. Each photographic session may last from a few minutes to several hours depending on the numbers of whales, the distribution of the group, and weather conditions. Thus, several individuals may be photographed more then once during a particular photographic session. We analyzed these pairs of photographs.

The distance moved, elapsed time, and direction and speed of movement were calculated for each successive pair of photographs provided that the second photograph was taken five (or more) minutes after the first photograph. Stepwise multiple regression techniques (using BMDP) were used to examine the relationship between the apparent speed of movement and elapsed time between photographs, water depth, distance from shore, ice cover, whale length and date. Whale speed and elapsed time were log transformed to normalize the distributions. Data from sessions where we judged the whales to be disturbed according to a number of behavioral criteria (see Koski and Johnson 1987) were analyzed separately from undisturbed data.

The location of each photograph was determined using the aircraft VLF (Very Low Frequency) navigation system, either a GNS-500A or a Collins LRN-70. Each location is subject to a small, random error inherent in the precision of

the VLF system. To minimize the effects of these random errors we did not use movement data from photographs taken less than five minutes apart. These biases are further minimized by using large samples of pairs of photographs. In these cases, the small, random errors tend to cancel each other out and prominent movement patterns can be discerned. We also eliminated a few cases where speeds greater than 12 km/h were indicated. We assumed that these represented errors in recording the aircraft position.

Interpretation of Data

Data from many photographic sessions in several geographic sections of the summering grounds taken in several years (primarily 1982, 1984, 1985, 1986) are grouped in the following analyses. Each data point consists of a minimum distance travelled (between two photographic locations) and an elapsed time (between the two photographs).

If whales tend to stay in a restricted location for several hours, the distances travelled will remain small and the rates of movement will decrease as elapsed time between photographs increases. This situation would occur if whales remained in a restricted area to feed. On the other hand, if whales constantly move from area to area, then the distance travelled should increase proportionally with the amount of time between photographs. The rate of movement should remain constant even as elapsed time increases. Thus, in the following analyses, distance travelled will not increase with elapsed time and rate of travel will decrease with elapsed time if the whales are sedentary and remain in one location for extended periods. If the whales move constantly, then it is expected that the distance travelled will increase directly as elapsed time increases and the rate of travel will remain steady or will decrease less rapidly than for sedentary animals.

Observed Micro-scale Movements

The minimum rates of movement and distance travelled were calculated for 510 pairs of photographs, each pair representing the same whale on the same day. Thirty-three of these pairs were obtained during sessions that we considered "disturbed" and were therefore not included in the following

analyses unless specifically stated otherwise. The shortest time between photographs included in the analysis was 5 min and the longest within-day interval between photographs was 4.4 hr. The shortest within-day distance moved was 0.06 km (less than the inherent error in the navigation system) and the longest was 19.1 km.

Figure 33 shows the relationship between the distance travelled and the elapsed time between photographs. The regularly increasing mean distance with increasing elapsed time indicates that, on the average, whale movements were not centered about one specific area. Instead, whales were gradually moving away from the locations where they were first photographed. The overall average rate of movement for 477 whales was 3.8 km/h.

The average rate of movement decreased with elapsed time between (Table 6). This is probably due to a complex of factors that include the proportionally larger effect of VLF navigation errors for short periods and small displacements; the possible disturbance effects of aircraft; and the effects of feeding dives back and forth across a specific feeding area that mask slower movements out of the area.

Table 6. Relationship between net rate of movement and elapsed time for rephotographed bowheads.

Elapsed Time (h)	Sample Size	Average Rate of Movement (km/h)
0.08-0.5	306	4.5
0.5-1.0	123	2.7
1.0-2.0	33	2.1
>2.0	15	2.1
	477	3.8

Stepwise multiple regression techniques were used to investigate the effects of water depth, distance from shore, ice cover, whale length and day of the year on distance travelled or net rate of movement. The logarithm of

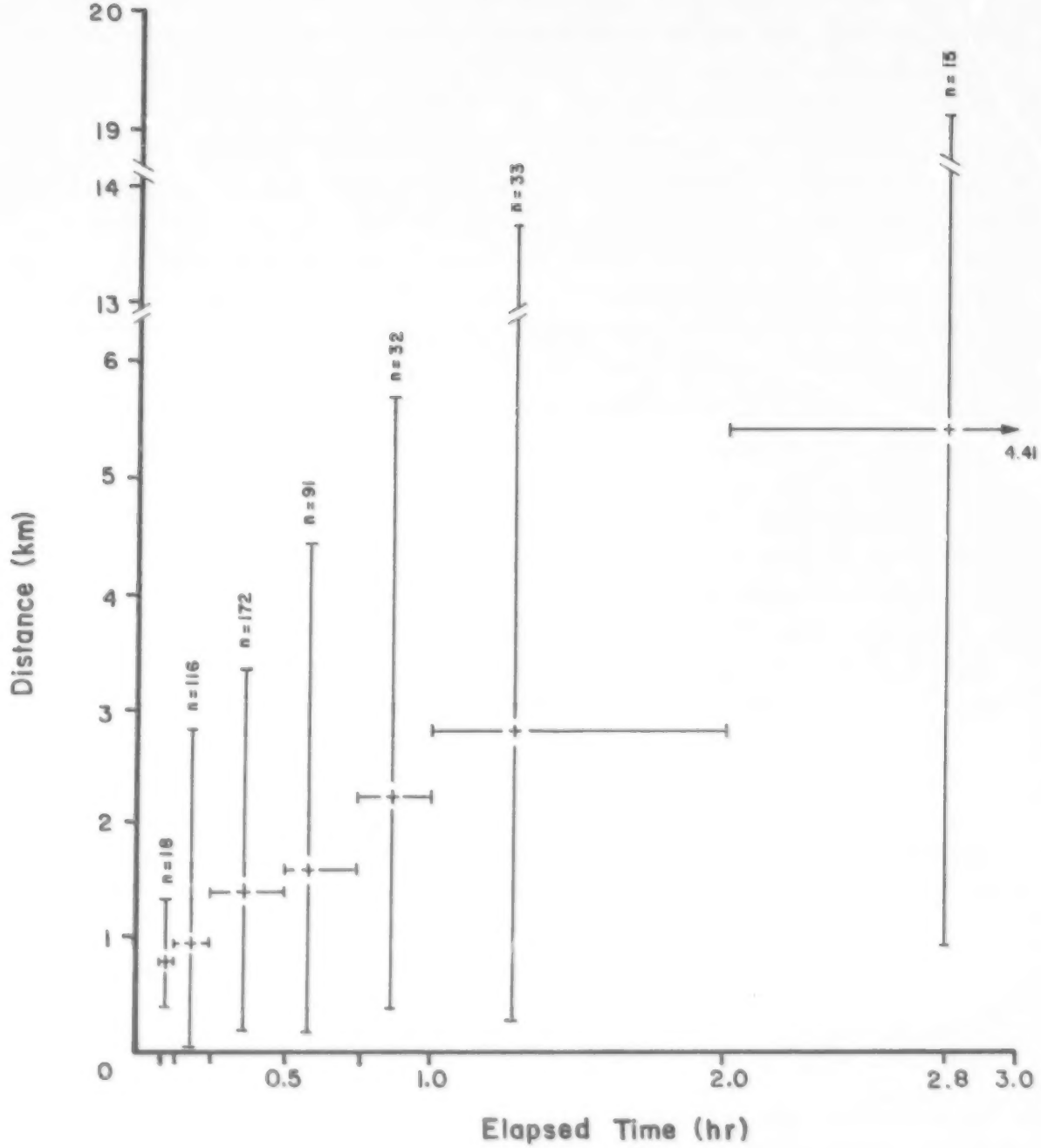


Figure 33. Relationship between distance travelled and elapsed time between successive photographs of the same whale. Vertical bar centred at mean value for time category. Length of vertical bar is the range of distance for that category. Horizontal bar is mean distance value in time category that is defined by length of the horizontal bar.

net whale speed was strongly and negatively correlated ($r = -0.52$; $p<0.001$; $df = 400$) with the log of the elapsed time. After this was taken into account no other factor significantly affected whale speed. Thus, the age (= length) of the whale and the depth of the feeding area did not seem to affect the rates of movement of whales over the short-term.

Net speeds (log transformed) in different geographic areas were compared using analysis of covariance with log elapsed time as the covariate. The results are summarized in Table 7. The observed mean speeds of movement of whales in Franklin Bay and along the Tuktoyaktuk Peninsula Shelf were significantly lower than in the King Point and Interface blocks after standardization for differences in elapsed time. The latter areas feature large numbers of subadult whales. A possible reason for their apparently high rates of movement is that they feed in concentrations of prey along the edge of the Mackenzie plume. These prey concentrations likely move rapidly in response to changes in localized oceanographic features. The adult whales in Franklin Bay and off the Tuktoyaktuk Peninsula may exploit more stable food sources. An additional possible explanation is that the subadult whales in the King Point and Interface zones were mostly in very shallow water, and seemed to be more sensitive to aircraft disturbance than were whales elsewhere (Richardson et al. 1985c). These two possible explanations are not mutually exclusive; both may have been involved.

Individual Movement Patterns

The previous paragraphs contain statistical analyses of all rephotographed whales. There are a few cases where individual whales were photographed three or more times at intervals greater than five minutes. These are summarized in Figures 34 and 35. The five situations illustrate a variety of short-term patterns ranging from basically straight-line movements (Fig. 34 upper and lower panels) to more complex back-and-forth movements (Fig. 35 upper). Figure 35 (lower panel) depicts the movements of three whales that apparently fed in a localized area before dispersing in different directions. Patterns that involve nearly complete reversals of direction suggest that whales are travelling back and forth through or along plankton concentrations.

Table 7. Comparisons of net speeds (log transformed) in all possible pairs of geographic areas[a] after standardization of elapsed time (log transformed) using the ANCOVA technique. Values in the triangular table are significance levels for the null hypothesis of no geographic difference in speed.

	EC Alaska	E Alaska	Komakuk	Herschel	King Point	Interface	Industrial Zone	Tuk. Shelf	Franklin Bay	Cape Parry	NC Amundsen
EC Alaska	1.0000										
E Alaska	0.3449	1.0000									
Komakuk	0.6765	0.4921	1.0000								
Herschel	0.2420	0.9928	0.3619	1.0000							
King Point	0.9285	0.2218	0.4843	0.0710	1.0000						
Interface	0.8381	0.2369	0.4879	0.1245	0.8628	1.0000					
Indust. Zone	0.9501	0.4492	0.7889	0.3821	0.8867	0.8151	1.0000				
Tuk. Shelf	0.0918	0.5966	0.1254	0.4880	**0.0202***	**0.0422***	0.1842	1.0000			
Franklin Bay	0.0804	0.5900	0.1084	0.4587	**0.0103***	**0.0311***	0.1758	0.9903	1.0000		
Cape Parry	0.2759	0.8073	0.3849	0.7719	0.1858	0.1941	0.3600	0.8496	0.8519	1.0000	
NC Amundsen	0.2333	0.7551	0.3303	0.7063	0.1394	0.1535	0.3197	0.8966	0.8991	0.9565	1.0000
Observed Mean Speed (km/h)	4.28	3.54	4.30	3.32	3.95	3.95	4.30	3.58	2.79	3.53	2.75
Adjusted Mean Speed[c] (km/h)	3.45	2.94	3.27	2.95	3.49	3.55	3.41	2.71	2.71	2.80	2.78
n[b]	29	21	57	58	126	39	16	39	50	14	16

[a] See Figures 6-8 for locations of the various Survey Blocks.
[b] Excludes 12 pairs of photographs from areas not included in Table.
[c] Adjusted to a standard elapsed time.
* Significant at the $p<0.05$ level.

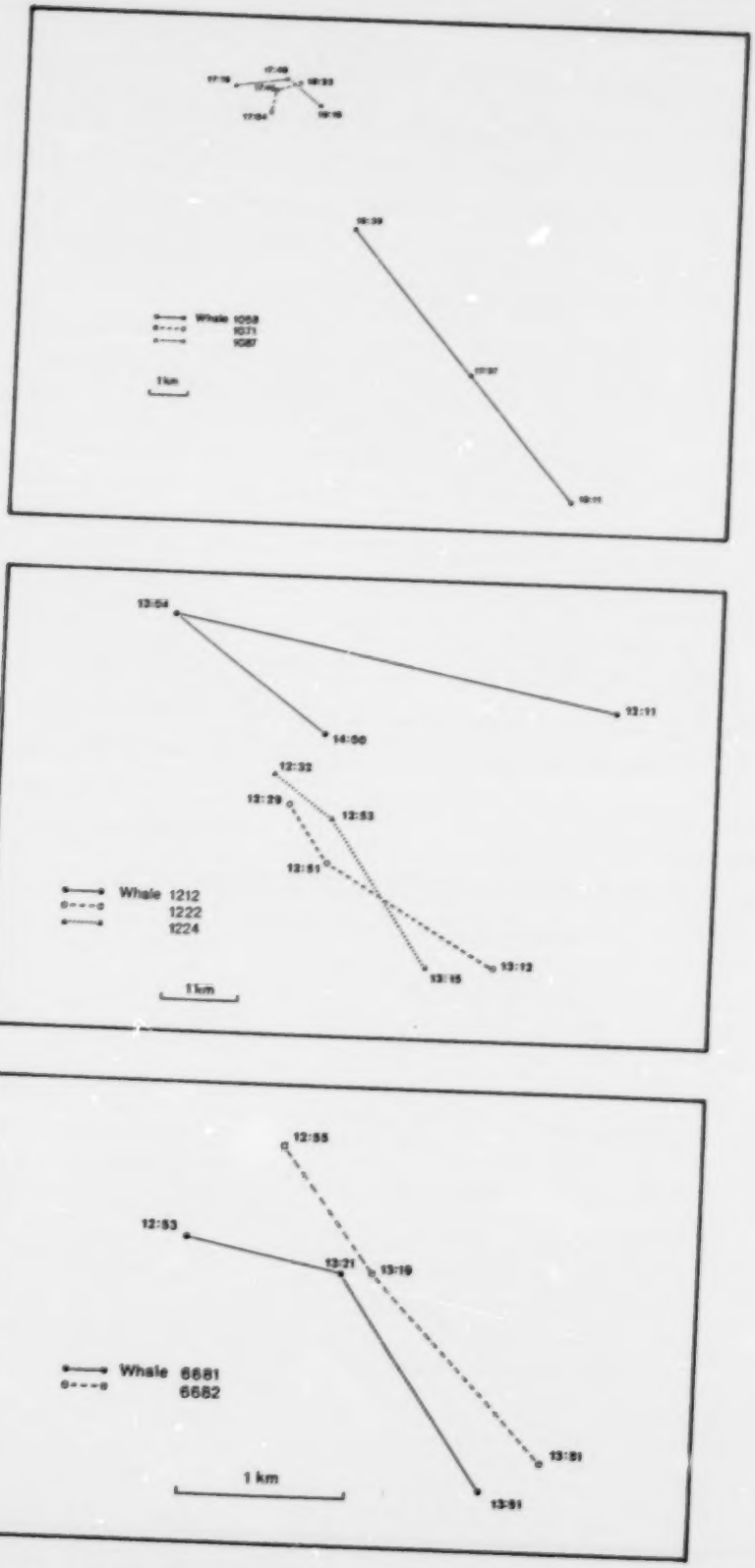


Figure 34. Tracks of bowhead whales photographed near Herschel Island on 16 (upper) and 18 (middle) August 1982 and in eastern Alaska on 22 September 1985 (lower).

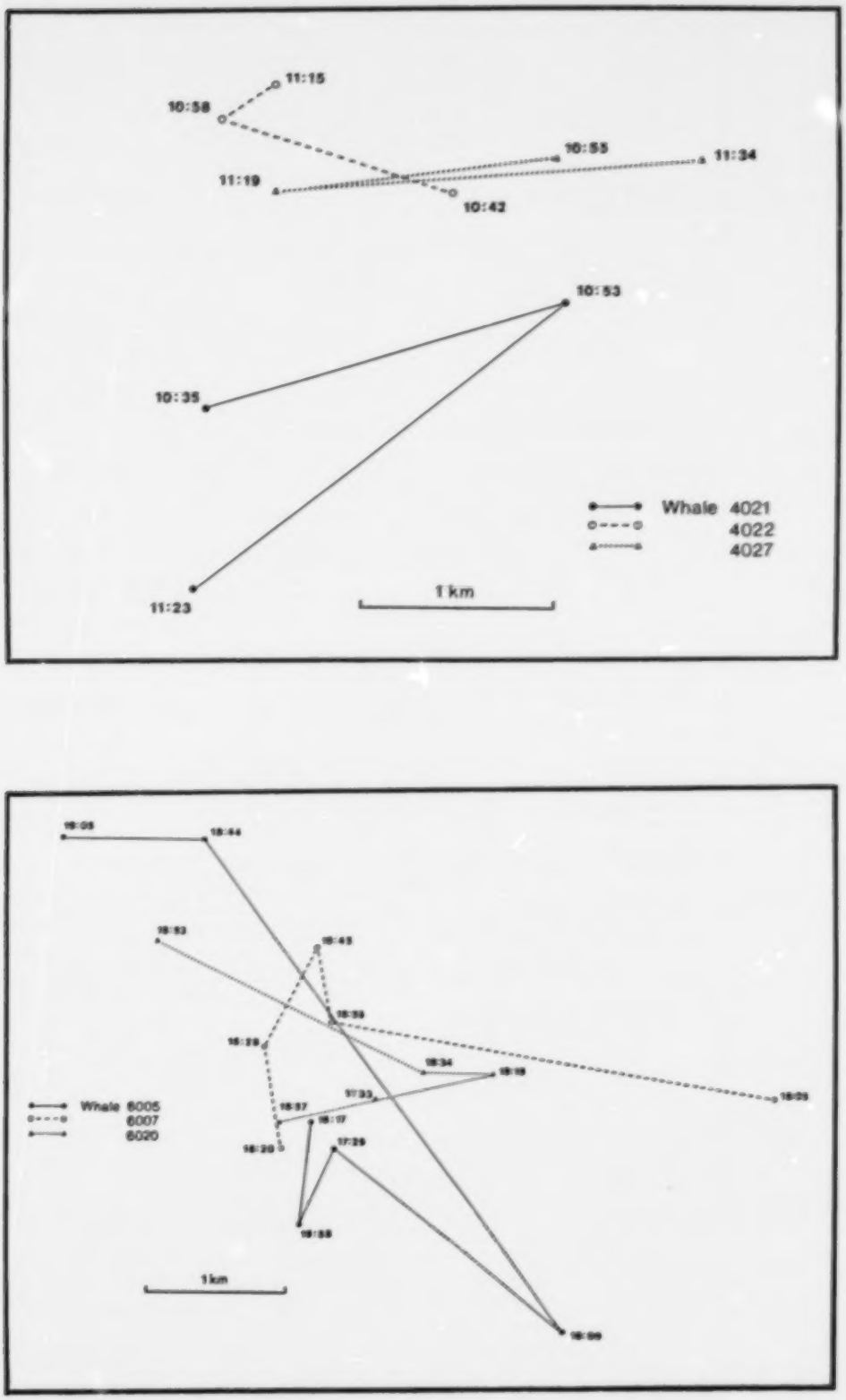


Figure 35. Tracks of bowhead whales photographed on 17 August 1984 in the Interface area (upper) and 13 September 1985 in the King Point area (lower).

The individual patterns demonstrate that microscale movements can be quite complex. Clearly, estimated net rates of movement based on only two points usually will be substantially smaller than estimates based on actual distances travelled. As an example, whale 4021 in Figure 35 (upper panel) travelled about 4.4 km from 10:35 to 10:53 to 11:23. However, if only photographs from 10:35 and 11:26 had been available, the estimate of distance travelled would have been about 1 km.

Conclusions

The data indicate that even over short periods of a few hours or less during the summer feeding season, bowheads often move into adjacent areas. The overall net speed was 3.8 km/h with stabilized net rates of about 2.1 km/h for periods of over one hour. Because whales often did not travel in straight lines, the net rates for intervals >1 hr are undoubtedly underestimates of actual average speed. These findings are important for any future evaluation of the effects of tanker traffic on whale distribution. Even in the absence of the tankers, individual whales can be expected to move several km in an hour or two. There is a danger of improperly classifying such movements as responses to tankers rather than as natural movements within or among feeding areas. The design of 'tanker effect' studies must allow for these patterns of local movement.

6. SITE FIDELITY WITHIN A SEASON

Since 1982 a number of bowhead photo-identification studies conducted in the Beaufort Sea and Amundsen Gulf have provided data on the locations of recognizable individuals on different days within a season (Davis et al. 1983, 1986a, 1986b; Richardson et al. 1987b). Data of this type can provide useful information about movements, residence times and site fidelity within a season. We have combined the inter-day resighting data from the above studies with the new inter-day resighting data obtained from the present study (Appendix 2). Data are presented on 83 bowheads that were photographed on more than one day during a season. Most (74--89%) of these individuals were photographed on two different days. Seven were photographed on three different days and two were photographed on four different days.

In the following sections we address the site fidelity of individual whales and their group stability. The Site Fidelity section addresses whether whales remain in the same area for prolonged periods of time. The group stability section examines whether whales move as groups or whether whale movements are independent of other whales in the group.

Site Fidelity

Some explanation is due the reader concerning how multiple (more than two day) resightings are presented. When a whale was photographed on three days (A, B and C) we broke the information down into the three component inter-day reidentifications that make up this resighting (A-B, B-C, and A-C). Similarly, for the two whales photographed on four days there are six components presented (A-B, B-C, C-D, A-C, A-D, B-D). Analyzed in this manner, the 83 whales were involved in 107 resightings. Seasonal site fidelity information is available from these inter-day reidentifications for whales first seen in seven of our study zones: North Central Amundsen, Franklin Bay, King Point, Interface, Herschel Island, Komakuk, and Eastern Alaska.

Amundsen Gulf

Three whales originally photographed in the North Central Amundsen Zone in early August 1985 were rephotographed later that year more than 600 km to the west in the Komakuk and Eastern Alaska Zones (Table 8). Two of these whales were rephotographed in late September, well after the start of the autumn migration out of the Canadian Beaufort Sea. These whales travelled at a minimum daily speed of about 13 km/day to arrive in the Komakuk and Eastern Alaska Zones by late September. This moderate rate of movement (about one-quarter of the maximum rates of movement we have observed) suggests that these whales probably lingered in these or other zones before they were re-photographed far to the west. The third whale arrived in the Komakuk Zone by 28 August and during the 25-day interval must have travelled an average of at least 26 km/day. All three of these whales were over 13 m in length, averaging 13.8 m.

Franklin Bay

Sixteen whales originally photographed in the Franklin Bay Zone in 1984 and 1985 were rephotographed on 22 different occasions (Table 9). All four of the 1984 resightings and 15 of 18 (83%) of the 1985 resightings occurred in Franklin Bay. The three whales resighted outside of the Franklin Bay Zone in 1985 were long distance (>450 km) resightings that occurred in late September in the Komakuk Zone. These movements clearly represent autumn migration out of Franklin Bay. One of these whales was photographed in Franklin Bay on both 24 August and 12 September and in the following 10 days travelled at a minimum rate of 47 km/day until it was resighted at Komakuk on 22 September. Since this speed is fairly close to our maximum observed rate of movement (60 km/day) this whale probably left Franklin Bay soon after 12 September.

Excluding the three autumn migration resightings, minimum daily rates of movement were low--averaging 2.8 km/day in 1984 and 4.3 in 1985. The number of days between resightings ranged from 5 to 14 (mean 10.5) in 1984 and 2-19 (mean 4.0) in 1985. The 19 day maximum residence time we observed involved the whale resighted once in Franklin Bay and then again in the Komakuk Zone. As already mentioned, this whale probably left Franklin Bay soon after 12

Table 8. Inter-day resightings originating in the North Central Amundsen Zone.

Year	No. Whales Resighted	Resightings	Original Sighting Date	Original Sighting Zone[a]	Resighting(s) Date	Resighting(s) Zone[a]	Minimum Distance Travelled (km)	No. Days Between Sightings	km/day
1985	1	1	3 Aug	NCA	28 Aug	K	640	25	25.6
"	1	1	3 Aug	NCA	22 Sep	K	638	50	12.8
"	1	1	3 Aug	NCA	29 Sep	EA	749	57	13.1
	3	3							

[a] NCA = North Central Amundsen, K = Komakuk, EA = Eastern Alaska. See Figures 6-8 for locations of these study blocks.

Table 9. Inter-day resightings originating in the Franklin Bay Zone.

Year	No. Whales Resighted	Resightings	Original Sighting Date	Original Sighting Zone[a]	Resighting(s) Date	Resighting(s) Zone[a]	Minimum Distance Travelled (km)	No. Days Between Sightings	km/day
1984	1	1	23 Aug	FB	1 Sep	FB	15	9	1.7
"	2	2	23 Aug	FB	6 Sep	FB	16-82	14	3.5
"	1	1	1 Sep	FB	6 Sep	FB	3	5	0.6
	4	4							
1985	1	1	20 Aug	FB	25 Aug	FB	37	5	7.4
"	1	1	21 Aug	FB	24 Aug	FB	10	3	3.3
"	3	3	21 Aug	FB	25 Aug	FB	5-44	4	5.2
"	1	1	21 Aug	FB	27 Aug	FB	11	6	1.8
"	4	4	24 Aug	FB	25 Aug	FB	2-9	1	6.4
"	3	3	24 Aug	FB	27 Aug	FB	5-6	3	1.9
"	1	1	24 Aug	FB	12 Sep	FB	86	19	4.5
"	-	1			22 Sep	K	473[b]	10	47.3
"	-	1	24 Aug	FB	22 Sep	K	559	29	19.3
"	1	1	25 Aug	FB	22 Sep	K	579	28	20.7
"	1	1	25 Aug	FB	27 Aug	FB	8	2	4.0
	16	18							

[a] FB = Franklin Bay, K = Komakuk. See Figures 7-8 for locations of these study blocks.
[b] Distance from previous resighting.

September. The average lengths of resighted Franklin Bay whales were 14.1 m in 1984 and 13.3 in 1985.

Franklin Bay whales exhibited strong seasonal site fidelity in the two years for which we have data. All of the whales originally sighted in Franklin Bay that were rephotographed prior to the start of the fall migration were rephotographed in Franklin Bay.

King Point and Interface Zones

We have combined the single Interface Zone resighting with the King Point resightings because the two zones are adjacent, have similar bathymetry, and are occupied by similar types of whales (mainly subadults). Inter-day resightings originating in these zones occurred in 1984, 1985 and 1986 and in total 26 whales were resighted 42 times (Table 10). Most of the resightings were recorded in 1985. We will summarize the 1985 data and then compare them to the 1984 and 1986 data.

In 1985, 34 of 39 resightings that originated in the King Point Zone were also resighted in the King Point Zone. If we eliminate the two bowheads resighted in the Komakuk Zone after 15 September (presumably autumn migrants), fully 92% (34 of 37) of the resightings occurred in the King Point Zone.

All of the 1985 movements out of the King Point Zone prior to autumn migration involved the same whale, photographed on four different days. This whale moved from the King Point Zone on 18 August to the Komakuk Zone by 28 August, to the Herschel Island Zone by 30 August and back into the King Point Zone by 6 September. All other resightings occurred in the King Point Zone. Overall, the 1985 King Point resightings demonstrated low net rates of movement, ranging from 0.5 to 47 km/day and averaging 5.8 km/day. The number of days between resightings ranged from 1 to 20 and averaged 6.9. The lengths of resighted King Point whales ranged from 7.7 to 13.1 m and averaged 10.9 m.

Only two 1984 inter-day resightings originated in the King Point Zone (Table 10). One of these whales (8.6 m) travelled a minimum of 120 km to the Komakuk Zone between 16 and 18 August, resulting in the fastest minimum rate

Table 10. Inter-day resightings originating in the King Point and Interface Zones.

Year	No. Whales Resighted	Resightings	Original Sighting Date	Original Sighting Zone[a]	Resighting(s) Date	Resighting(s) Zone[a]	Minimum Distance Travelled (km)	No. Days Between Sightings	km/day
1984	1	1	16 Aug	KP	18 Aug	K	120	2	60.0
"	1	1	30 Aug	KP	2 Sep	KP	26	3	8.7
	2	2							
1985	1	1	15 Aug	KP	18 Aug	KP	26	3	8.7
"	1	1	18 Aug	KP	28 Aug	K	111	10	11.1
"	-	1			30 Aug	HI	63[b]	2	31.5
"	-	1			6 Sep	KP	70[b]	7	10.0
"	-	1	18 Aug	KP	30 Aug	HI	174	12	14.5
"	-	1	18 Aug	KP	6 Sep	KP	244	19	12.8
"	-	1	28 Aug	K	6 Sep	KP	133	9	14.7
"	1	1	25 Aug	KP[c]	27 Aug	KP	3	2	1.5
"	1	1	25 Aug	KP[c]	27 Aug	KP	2	2	1.0
"	-	1			6 Sep	KP	15[b]	10	1.5
"	-	1	25 Aug	KP[c]	6 Sep	KP	16	12	1.3
"	1	1	25 Aug	KP[c]	27 Aug	KP	14	2	7.0
"	-	1			30 Aug	KP	30[b]	3	10.0
"	-	1			6 Sep	KP	40[b]	7	5.7
"	-	1	25 Aug	KP[c]	30 Aug	KP	17	5	3.4
"	-	1	25 Aug	KP[c]	6 Sep	KP	31	12	2.6
"	-	1	27 Aug	KP	6 Sep	KP	24	10	2.4
"	1	1	25 Aug	KP[c]	6 Sep	KP	8	12	0.7
"	1	1	25 Aug	KP[c]	13 Sep	KP	37	19	1.9
"	-	1			14 Sep	KP	47[b]	1	47.0
"	-	1	25 Aug	KP[c]	14 Sep	KP	10	20	0.5
"	1	1	27 Aug	KP	30 Aug	KP	28	3	9.3
"	1	1	30 Aug	KP	31 Aug	KP	9	1	9.0
"	4	4	30 Aug	KP	6 Sep	KP	7-32	7	2.8
"	1	1	30 Aug	KP	14 Sep	KP	23	15	1.5
"	1	1	3 Sep	KP	6 Sep	KP	26	3	8.7
"	1	1	6 Sep	KP	13 Sep	KP	54	7	7.7
"	-	1			14 Sep	KP	37[b]	1	37.0
"	-	1	6 Sep	KP	14 Sep	KP	27	8	3.4
"	1	1	6 Sep	KP	14 Sep	KP	22	8	2.8
"	1	1	6 Sep	KP	22 Sep	K	112	16	7.0
"	1	1	6 Sep	KP	24 Sep	K	123	18	6.8
"	4	4	13 Sep	KP	14 Sep	KP	13-33	1	19.0
1986	1	1	26 Aug	I[c]	15 Sep	K	133	20	6.6
	23	39							

[a] KP = King Point; K = Komakuk; HI = Herschel Island; I = Interface. See Figure 7 for locations of these study blocks.
[b] Distance from previous resighting.
[c] CRC photographs.

of movement we observed (60 km/day). The other whale (11.8 m) travelled 26 km in three days (30 August-2 September) and was rephotographed in the King Point Zone.

The single 1986 resighting in this area originated in the Interface Zone. It involved a 10.8 m whale first photographed on 26 August 1986. It was rephotographed 20 days later (15 September) in the Komakuk Zone 133 km to the west and travelled at a minimum rate of 6.6 km/day. This movement probably represents autumn migration by this individual.

Herschel Island

A total of 18 inter-day resightings originated in the Herschel Island Zone in 1982, 1984 and 1985 (Table 11). Most of these resightings occurred in 1982. Only two of the 16 1982 resightings involved whales that were rephotographed outside the Herschel Island Zone. One whale, first photographed on 16 August, moved into the Offshore Yukon Zone, a distance of 82 miles, by 4 September. Another whale travelled a distance of about 150 km from the Herschel Island Zone on 18 August into the Delta Shelfbreak Zone by 23 August. It was photographed again on 5 September back in the Herschel Island Zone only about 21 km from where it was first photographed. The remaining whales were all resighted in the Herschel Island Zone. Overall, in 1982 minimum rates of movement were low, ranging from 1.2 to 30.8 km/day and averaging 5.4. Resighting periods ranged from 1 to 19 days and averaged 6.2. The lengths of resighted Herschel Island whales in 1982 ranged from 11 to 15.4 m and averaged 13.1 m.

Single resightings originated in the Herschel Island Zone in 1984 and 1985 (Table 11). Both of these resightings involved individuals that were rephotographed outside the Herschel Island Zone. In 1984 an 8.6 m whale photographed in the Herschel Island Zone on 17 August was rephotographed the following day 57 km to the south in the King Point Zone. The 1985 resighting involved a 9.8 m whale that was photographed in the Herschel Island Zone on 19 August, and then again one day later in the Interface Zone, having travelled a distance of 21 km. Few whales were recorded in the Herschel Island Zone in

Table 11. Inter-day resightings originating in the Herschel Island Zone.

Year	No. Whales Resighted	Resightings	Original Sighting Date	Original Sighting Zone[a]	Resighting(s) Date	Resighting(s) Zone[a]	Minimum Distance Travelled (km)	No. Days Between Sightings	km/day
1982	9	9	16 Aug	HI	18 Aug	HI	3-17	2	4.3
"	1	1	16 Aug	HI	4 Sep	HI	38	19	2.0
"	1	1	16 Aug	HI	4 Sep	OY	82	19	4.3
"	1	1	18 Aug	HI	23 Aug	DS	154	5	30.8
"	-	1			5 Sep	HI	147[b]	13	11.3
"	-	1	18 Aug	HI	5 Sep	HI	21	18	1.2
"	1	1	18 Aug	HI	24 Aug	HI	9	6	1.5
"	1	1	4 Sep	HI	5 Sep	HI	8	1	8.0
	14	16							
1984	1	1	17 Aug	HI	18 Aug	KP	57	1	57.0
1985	1	1	19 Aug	HI[c]	20 Aug	I[c]	21	1	21.0

[a] HI = Herschel Island, OY = Offshore Yukon, DS = Delta Shelfbreak. See Figure 7 for locations of these study blocks.
[b] Distance from previous resighting.
[c] CRC photographs.

1984 and 1985 and the few resightings suggest that use of the area in those years was transitory.

Komakuk

Fourteen whales originally sighted in the Komakuk Zone were resighted 18 times in 1985 and 1986 (Table 12). Although six of these whales were resighted on or after 15 September when westward migration may have begun, only the latest resightings (1 October) involved whales rephotographed outside the Komakuk Zone. These resightings were of a cow-calf pair that moved westward from the Komakuk Zone where they were first photographed on 27 September to the East Central Alaska Zone on 1 October--a distance of 212 km. This pair moved at a minimum rate of 53 km/day.

Excluding these autumn migrants, minimum rates of movement were the lowest observed in any study zone, averaging only 1.3 km/day (range 0.2-4.8) in 1985 and 1.9 km/day (range 1.0-2.1) in 1986. All of the resightings involved whales photographed rather late in the year--28 August was the earliest. The longest residence period observed was 16 days (28 August-13 September) in 1985 and 14 days (5-19 September) in 1986.

Although these data suggest strong seasonal site fidelity in the Komakuk Zone, this may only be the pattern in late August and early to mid September. Limited evidence from resightings of a whale originally photographed in another zone suggests that earlier in the season use of this zone is transitory. One whale photographed in the King Point Zone on 18 August 1985 was rephotographed on 28 August in the Komakuk Zone. It was still later rephotographed in the Herschel Island Zone (30 August) and finally back in the King Point Zone (6 September). Two other whales arrived at the Komakuk Zone in mid-to-late August from other zones. A whale first photographed in the North Central Amundsen Zone on 3 August 1985 was photographed 25 days later on 28 August in the Komakuk Zone. In 1985, a whale first photographed in the King Point Zone on 16 August was rephotographed two days later in the Komakuk Zone.

Table 12. Inter-day resightings originating in the Komakuk Zone.

Year	No. Whales Resighted	Resightings	Original Sighting Date	Original Sighting Zone[a]	Resighting(s) Date	Resighting(s) Zone[a]	Minimum Distance Travelled (km)	No. Days Between Sightings	km/day
1985	1	1	28 Aug	K	8 Sep	K	2	11	0.2
"	1	1	28 Aug	K	8 Sep	K	12	11	1.1
"	-	1			13 Sep	K	24[b]	5	4.8
"	-	1	28 Aug	K	13 Sep	K	13	16	0.8
"	2	2	8 Sep	K	11 Sep	K	4	3	1.5
"	1	1	8 Sep	K	13 Sep	K	6	5	1.2
"	1	1	8 Sep	K	22 Sep	K	66	14	4.7
"	1	1	11 Sep	K	13 Sep	K	6	2	3.0
"	1	1	13 Sep	K	24 Sep	K	23	11	2.1
	8	10							
1986	1	1	5 Sep	K	6 Sep	K	1	1	1.0
"	-	1			14 Sep	K	17[b]	8	2.1
"	-	1	5 Sep	K	14 Sep	K	16	9	2.1
"	1	1	5 Sep	K	14 Sep	K	17	9	1.9
"	1	1	5 Sep	K	19 Sep	K	32	14	2.3
"	1	1	14 Sep	K	15 Sep	K	6	1	6.0
"	2	2[c]	27 Sep	K	1 Oct	ECA	212[c]	4	53.0
	6	8							

[a] K = Komakuk, ECA = East Central Alaska. See Figures 6-7 for locations of these study blocks.
[b] Distance from previous resighting.
[c] Cow-calf pair travelling together.

Additionally, a number of whales resighted at Komakuk in mid-to-late September were originally photographed in other zones. These whales were first photographed in the North Central Amundsen (1--1985), Franklin Bay (3--1985), King Point (2--1985), and Interface (1--1986) Zones. This area may have been an important feeding area for migrating whales in mid-to-late September 1985 (see Richardson et al. 1987b).

In summary, it appears that in certain years nearshore waters around Komakuk are used in late summer by subadult whales for feeding. Many of these whales appear to be quite sedentary during the late August-mid September period. At least some of these whales move into the Komakuk area from points farther east. A small proportion may use the Komakuk area only briefly and then return to feeding areas elsewhere. In mid-to-late September, a separate group of whales, many of them large adults (some with calves) travel west through the Komakuk zone, mostly farther offshore, and sometimes stopping to feed at least briefly. Some of these whales had been identified earlier in the summer at a wide range of locations extending from the Amundsen Gulf to the King Point regions.

Eastern Alaska

Six whales were resighted in this area six times during a brief period in early September 1986 (Table 13). Richardson et al. (1987b) recorded the presence of bowheads near the Kongakuk River Delta for five days. They were photographed on 4, 5, 6 and 7 September. The resighted whales were subadults (mean length 11.0 m). They travelled short distances (1-13 km) at an average rate of 4.4 km/day.

Stability of Group Composition

In the preceding section we analyzed inter-day movements of individual whales. In this section we will use the same data to try to determine whether groups of whales maintain the same composition as individuals move about in the study area. Do whales photographed in one photo-session tend to be resighted in association with the same whales on a later date? This question is assessed by examining detailed maps showing movements of re-identified

Table 13. Inter-day resightings originating in the Eastern Alaska Zone.

Year	No. Whales Resighted	Resightings	Original Sighting Date	Original Sighting Zone[a]	Resighting(s) Date	Resighting(s) Zone[a]	Minimum Distance Travelled (km)	No. Days Between Sightings	km/day
1986	3	3	5 Sep	EA	6 Sep	EA	1-3	1	1.7
"	3	3	5 Sep	EA	7 Sep	EA	10-13	2	5.8
	6	6							

[a] EA = Eastern Alaska. See Figure 6 for location of this study block.

whales that were photographed on the same dates. A number of such cases exist for each of the study zones where fairly large samples of inter-day re-identifications occurred in a given year.

Franklin Bay

In 1984, two of the four inter-day Franklin Bay resightings involved whales that were photographed on the same day (Table 9). The two were first photographed on 23 August and were rephotographed on 6 September (Fig. 36). The whales were about 95 km apart on 23 August. One 14.1 m whale was originally photographed in a group of 25-40 whales near Baillie Islands. This whale travelled 16 km to the SSE to arrive at the 6 September location. The other whale (13.7 m) was first photographed off the mouth of the Horton River among a group of 10 whales. It travelled about 82 km to the NNW where it was photographed with the other whale among a group estimated to number 25 whales.

We obtained photographs of most, if not all, of the whales in the two 23 August photo-sessions from which these resightings originated. We obtained A or B (re-identifiable between years and days, respectively) photographs of 33 different whales from the group of 25-40 whales, and 10 from the group estimated to contain 10 whales. On 6 September we obtained A and B photographs of 33 different whales from the group originally estimated to consist of 25 whales. Because the photographic coverage of these groups was so complete, it seems clear that few, if any, of the other whales photographed on 23 August were among the group photographed on 6 September.

In 1985, three whales photographed on 21 August were also photographed on 25 August (Fig. 37). Two whales (11.0 and 14.4 m) photographed together on 21 August in SW Franklin Bay (among a group of nine whales) were rephotographed in different areas. The 11.0 m whale travelled 44 km to the NNE (photographed in a group of 10 whales) while the 14.4 m whale remained near the original location, part of a group of eight whales. The third whale (13.1 m) travelled from a second 21 August location (group size 20 whales) NNW to the same 25 August location as the 11 m whale (10 whales in group). Thus, the two whales photographed together on 21 August had separated by 25 August and a third whale at a second location joined one of the other two on 25 August.

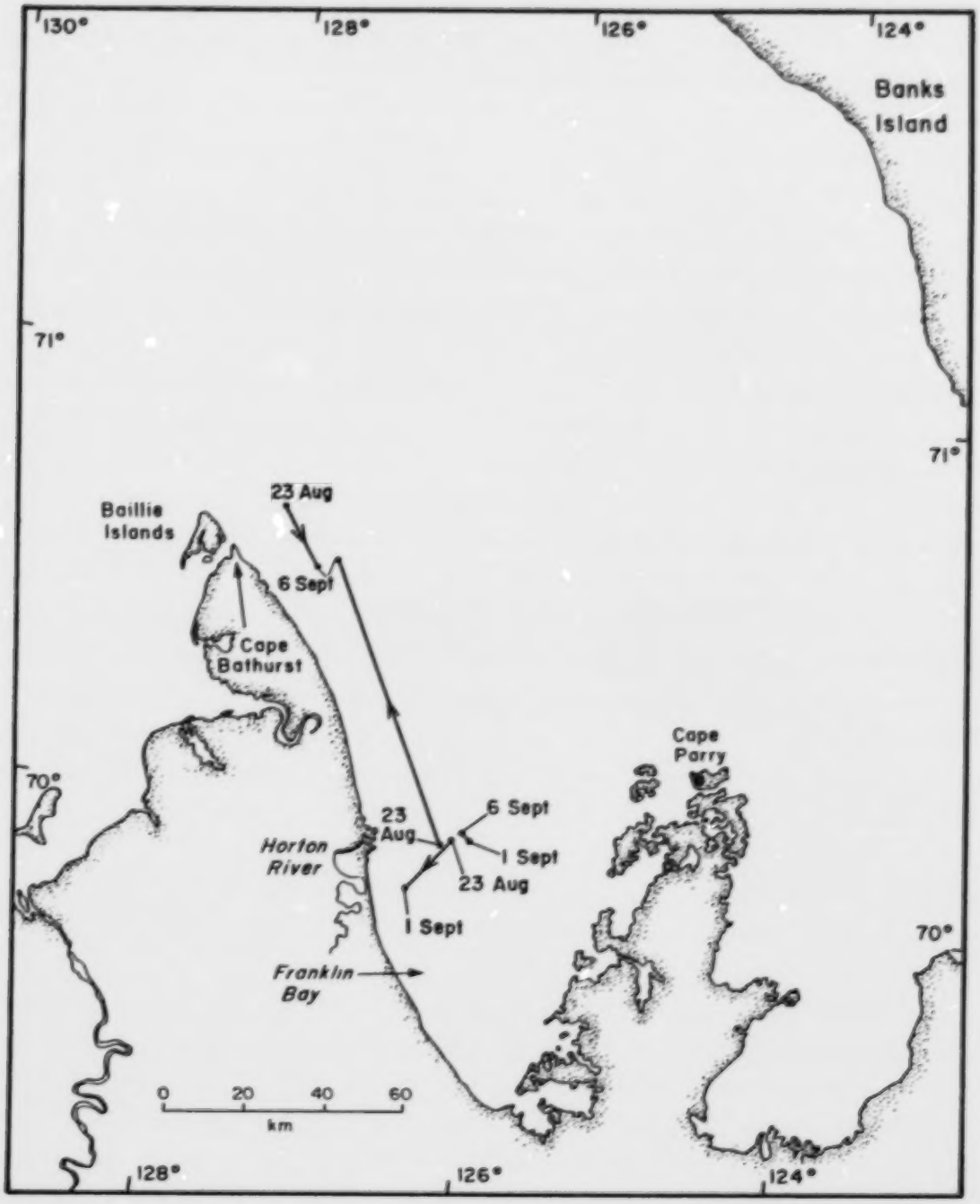


Figure 36. Locations in Franklin Bay of between-day resightings in 1984.

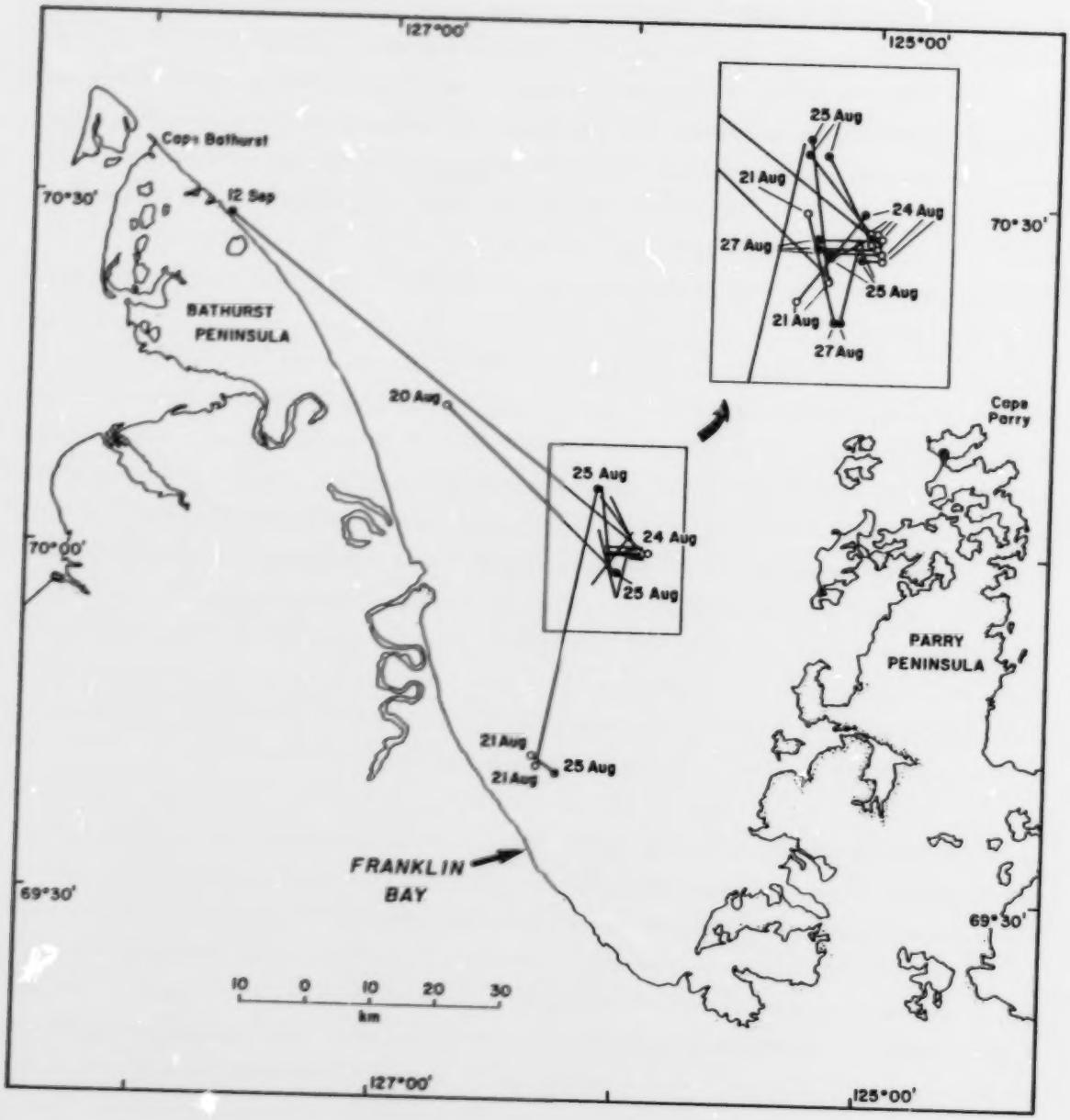


Figure 37. Inter-day movements of bowheads rephotographed in Franklin Bay in 1985. Open circles show the locations of the original photographs; closed circles show the locations of the resightings.

On 21 August we photographed four different re-identifiable whales from a the group of nine whales that included the two that were resighted on 25 August. We had nearly complete photographic coverage of the groups that these two whales were resighted with on 25 August (re-identifiable photographs of nine different whales in the group of 10 and eight different whales in the group of eight). Thus, the other two re-identifiable whales from the group these resightings originated from were not resighted in either of the groups that the resightings occurred in on 25 August. The third whale involved in resightings on these dates was first photographed in a group of 20 whales from which we obtained re-identifiable photographs of 10. Nine of these 10 whales were not resighted on 25 August among the seven other re-identifiable that were photographed.

Seven whales photographed together on 24 August (20 whales in group) were rephotographed on 25 (four whales) and 27 (three whales) August. Four whales (13.4, 13.4, 13.5 and 13.7 m) were rephotographed on 25 August in two different groups estimated to consist of nine and 10 whales. These two groups were about 11 km apart on 25 August. Three other whales (12.2, 13.2 and 13.7 m) photographed in the same 24 August location were rephotographed together on 27 August about 6 km west of the 24 August location in a group of nine individuals. Thus, the resighted whales that were originally photographed were resighted in three different groups, but all three of these groups contained more than one individual from the original (24 August) sighting.

On 24 August we obtained photographs of 18 re-identifiable whales from the group of 20 whales that included the 7 that were rephotographed on 25 and 27 August. Photographic coverage of the two 25 August groups in which the resighted whales occurred was good: re-identifiable photographs of 9 and 8 different whales were obtained from the groups estimated to consist of 10 and 9 individuals, respectively. Thus, 14 re-identifiable whales photographed on 24 August (including those resighted on 27 August) were not resighted in the two groups photographed on 25 August. On 27 August we obtained re-identifiable photographs of 8 of 9 whales estimated to be in the group that included three resighted whales. Thus, 15 of the identifiable whales photographed on 24 August were not resighted in the group photographed on 27 August.

To summarize the Franklin Bay resightings, in 1984 over a 14 day period (23 August-6 September) two whales were photographed apart and then together. In 1985, over a one-day period (24-25 August) four whales photographed together were rephotographed in two groups (each group with at least two of the original whales). Over a three-day period (24-27 August) three whales remained together. Finally, over a four-day period (21-25 August) two whales first photographed together were later photographed apart, while another whale, photographed apart from the first two was later photographed with one of them.

King Point

In 1985, five whales photographed within two different parts of the King Point Zone on 30 August were rephotographed 7 days later on 6 September (Table 10). Three whales (12.6, 10.3 and 7.7 m) were first photographed E of Kay Point (Fig. 38) among a group of 80 whales. The other two whales (12.4 and 9.0 m) were first photographed in a group of about 60 whales 12 km east of King Point. All of these whales were rephotographed on 6 September along a line extending NNE from the coast a few km west of Shingle Point. This assemblage on 6 September was estimated to include about 750 whales.

We obtained good photographic coverage of the two 30 August groups that involved resightings on 6 September. Photographs of 64 re-identifiable whales were obtained from the group of 80 whales photographed east of Kay Point. Photographs of 51 re-identifiable whales were obtained from the group of 60 whales east of King Point. Coverage on 6 September, however, was limited relative to the number of whales estimated to be present. Photographs of 145 re-identifiable whale were obtained from a group estimated to consist of 750 whales (19.3% coverage). Thus, many of the re-identifiable whales photographed on 30 August may have been present, but not photographed during the 6 September photo session.

Similarly, on 13 September six whales photographed in two different locations coalesced into a single group on 14 September (Fig. 39). Three whales (10.7, 11.2 and 13.1 m) photographed in a group of about 65-70 whales 17 km NW of Kay Point travelled about 30 km to the SW. The three other whales

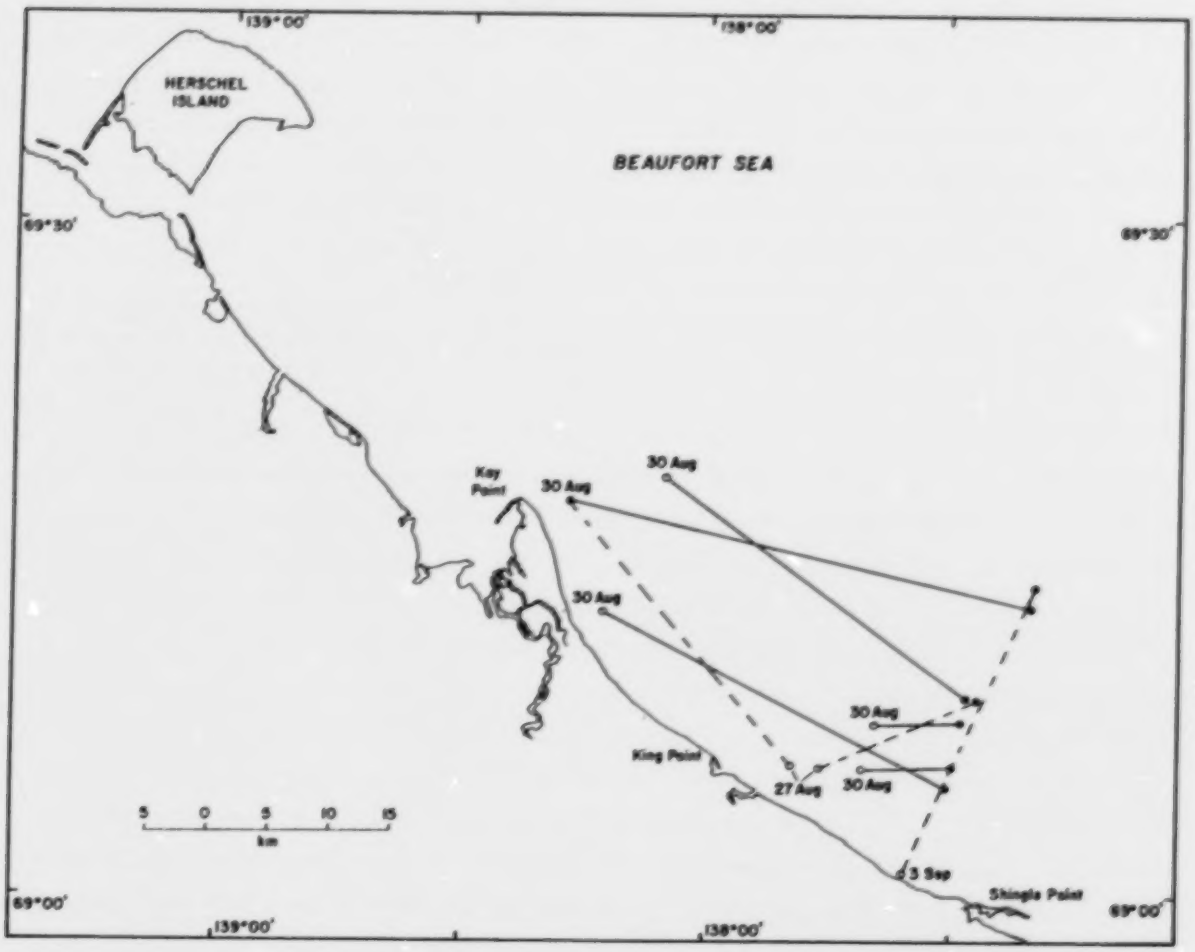


Figure 38. Inter-day movements of bowheads rephotographed in the King Point Zone on 6 September 1985. Open circles show the locations of the original photographs; closed circles (unless otherwise indicated) show the locations where the whales were rephotographed on 6 September.

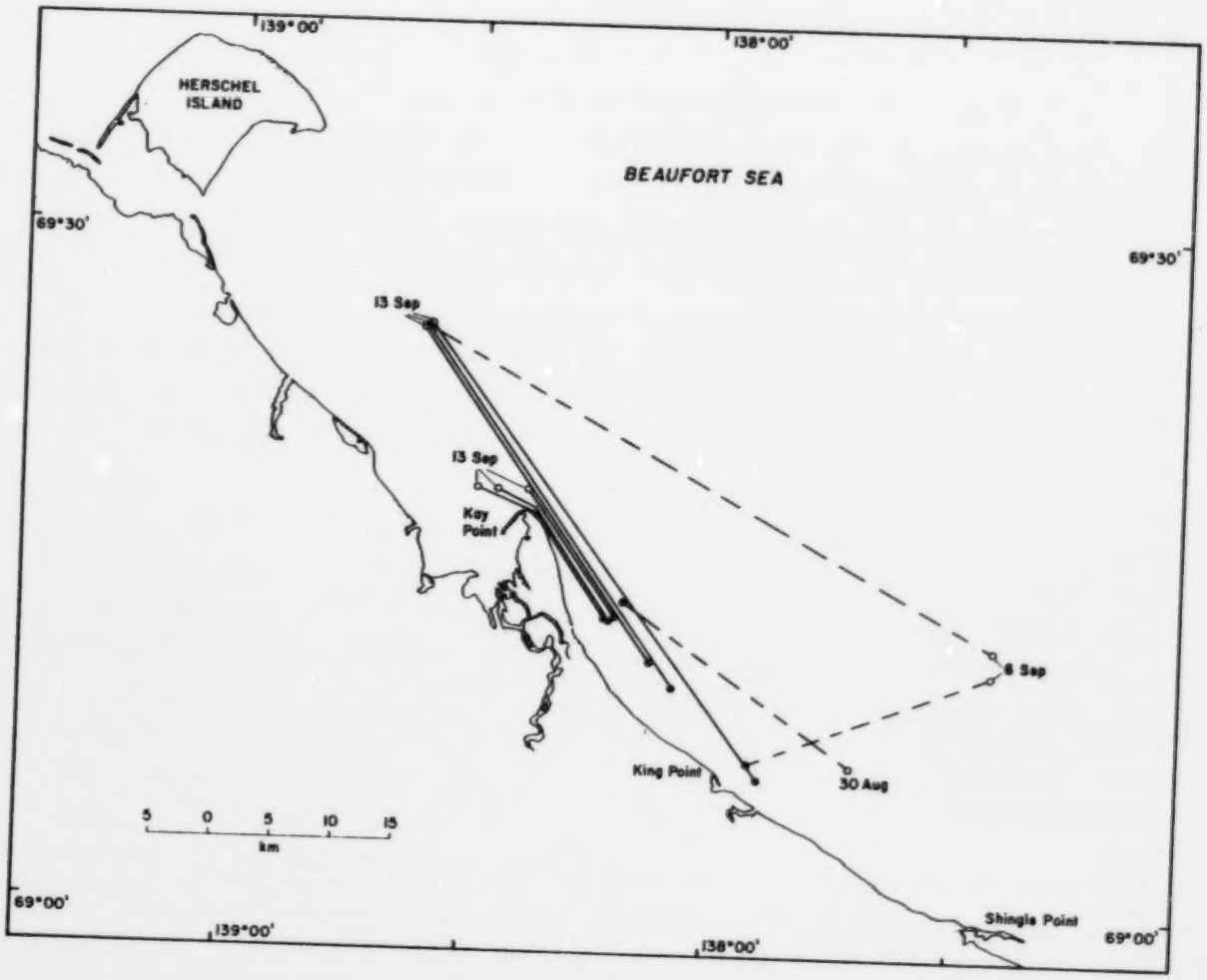


Figure 39. Inter-day movements of bowheads rephotographed in the King Point Zone, on 14 September 1985. Open circles show the locations where the whales were first photographed; closed circles (unless otherwise indicated) show the locations where the whales were rephotographed on 14 September.

(8.9, 10.8 and 11.3 m) first photographed near Kay Point among a group of 25-30 whales travelled about 14 km to the SW where they became part of the same group (85-90 whales) as the other three.

Good photographic coverage was obtained of only one of the three groups involved in the 13-14 September resightings. We obtained re-identifiable photographs of 27 different whales from the group of 25-30 whales near Kay Point on 13 September. Re-identifiable photographs of only 18 different whales were obtained for the group of 65-70 whales photographed NW of Kay Point on that date. We obtained re-identifiable photographs for only about one-half (42) of the whales (85-90) estimated to be present in the group photographed on 14 September. Thus, some of the recognizable whales photographed on 13 September may have been present, but not photographed, on 14 September.

To summarize the King Point data, on two occasions we observed individuals that were originally in two groups of whales later associating more closely with each other in a larger group of whales. This was observed over a one-day resighting period (13-14 September--6 whales) and over a seven-day period (30 August-6 September--5 whales).

Herschel Island

In 1982, 11 whales (13.1 m mean length, range 11.0-14.7 m) involved in inter-day resightings were first photographed on 16 August in an area where about 250 whales were present. Two days later nine of these whales were rephotographed an average of nine km SE of the original location (Table 11; Fig. 40). These nine rephotographed whales were among an estimated 100 whales. Two other whales photographed near one another on 16 August were rephotographed on 4 September (Fig. 41). Both of these whales had moved north during the 19 day resighting period, but they had separated to locations more than 50 km apart. Thus, of the 11 whale photographed on 16 August that were resighted later, nine were rephotographed together two days later on 18 August and two others were rephotographed elsewhere and apart on 4 September (19 days later).

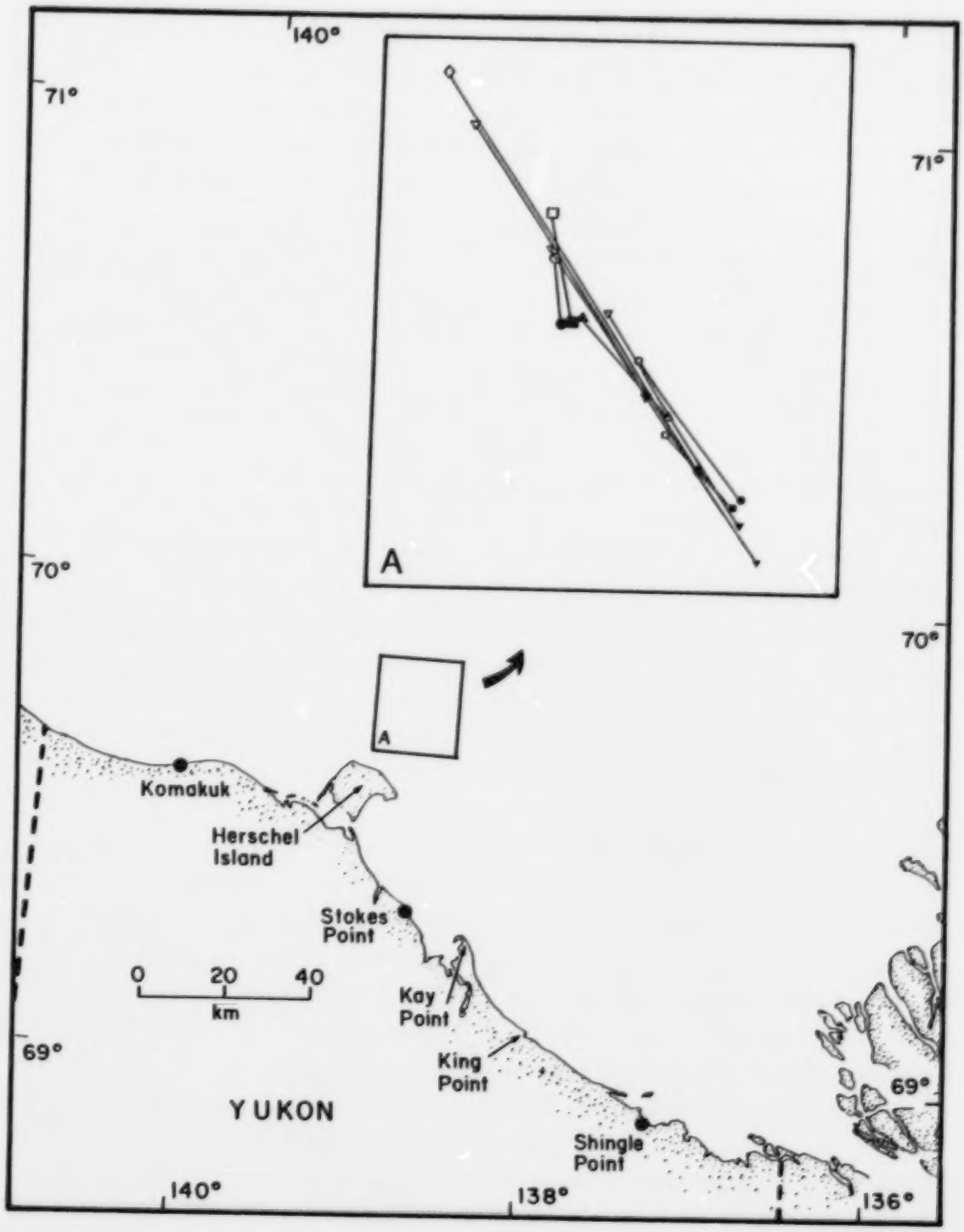


Figure 40. Inter-day movements of whales photographed on 16 and 18 August 1982 in the Herschel Island Zone. Open symbols indicate 16 August locations; solid symbols show the 18 August resightings (see Figure 41 for resightings on the other days in 1982.

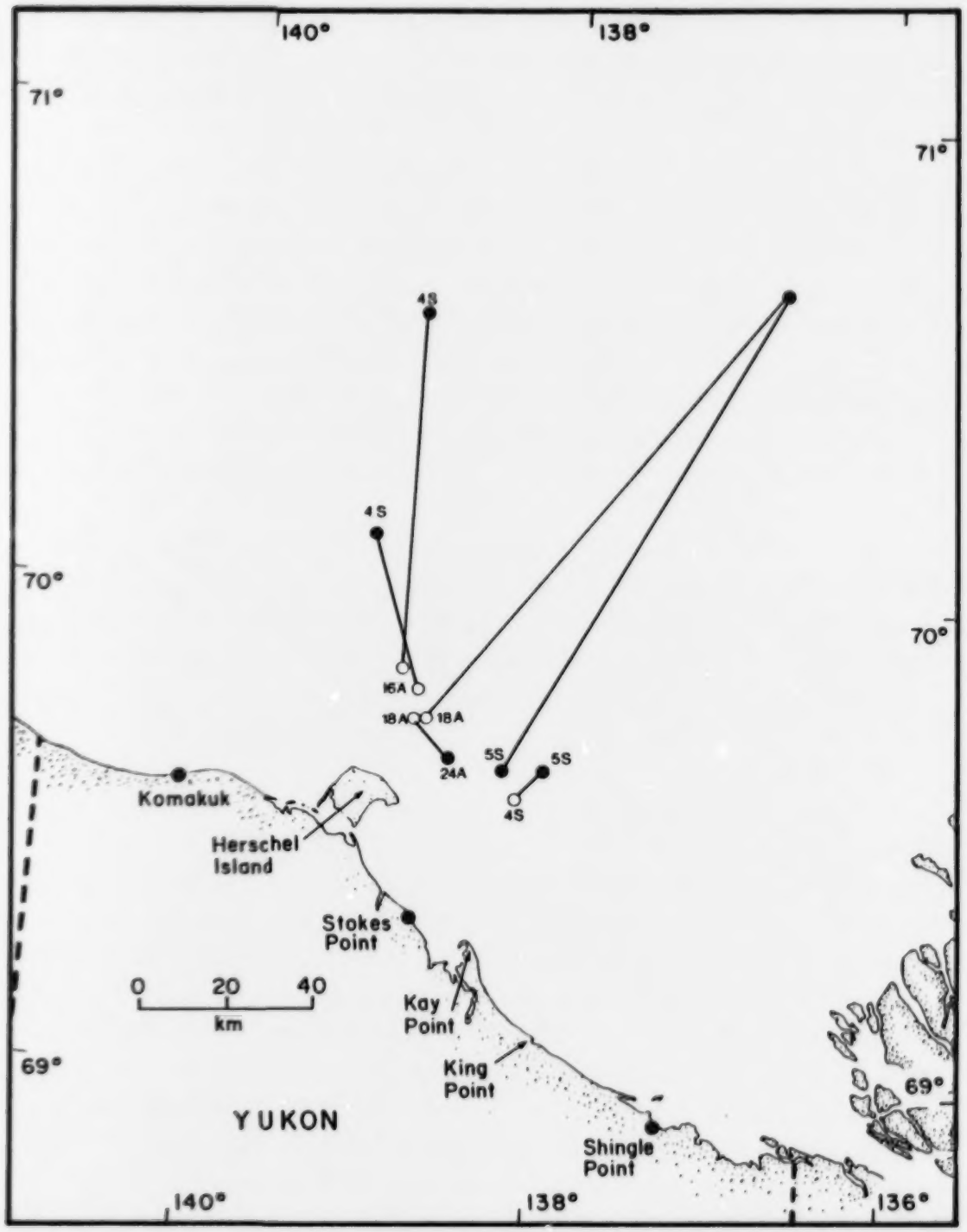


Figure 41. Inter-day movements of whales photographed in the Herschel Island Zone in 1982. Open circles indicate original sighting locations, solid circles show resighting locations. (All 16-18 August resightings in this Zone are shown in Figure 40.)

We obtained re-identifiable photographs of 128 of the 250 whales estimated to be present on 16 August. On 18 August we obtained re-identifiable photographs of 67 different whales from a group estimated to contain 100 individuals. Thus, many (119) re-identifiable whales photographed on 16 August were not resighted on 18 August. On 4 September we obtained re-identifiable photographs of 13 and four different whales from the two groups where whales originally photographed on 16 August were resighted. Again, large numbers of re-identifiable whales photographed on 16 August were not resighted in these two groups.

Komakuk

In 1985, two whales were photographed on both 28 August and 8 September. One of these whales was also photographed on 13 September, and this resighting (8-13 September) corresponded with the resighting dates of a third whale (Table 12). The 12.8 m whale photographed on three dates was photographed 12 km NW of Komakuk on 28 August, in a group of 25 whales (Fig. 42). This location was about 10 km west of the second whale (13.7 m), which was photographed in a group of 16 whales north of Komakuk. Eleven days later (8 September) the two whales were rephotographed together in a group of 45-50 whales, only 2 km from the 28 August location of the second whale.

A third whale (13.1 m) was photographed at the same 8 September location as the other two whales. Five days later on 13 September this whale and the 12.8 m whale photographed on 28 August and 8 September were about 27 km apart. The 12.8 m whale had moved about 24 km west and the 13.1 m whale had moved 6 km to the east. To summarize these Komakuk resightings, two whales photographed apart on 28 August were photographed together 11 days later on 8 September. One of these whales was photographed together with another whale on 8 September, but apart from it five days later on 13 September.

The two resighted whales that were originally photographed on 28 August were in groups for which we obtained good photographic coverage. We took re-identifiable photographs of 17 of the estimated 25 whales present in the group 12 km NW of Komakuk. We obtained re-identifiable photographs of 17 whales from the group north of Komakuk originally estimated to contain 16 whales. However,

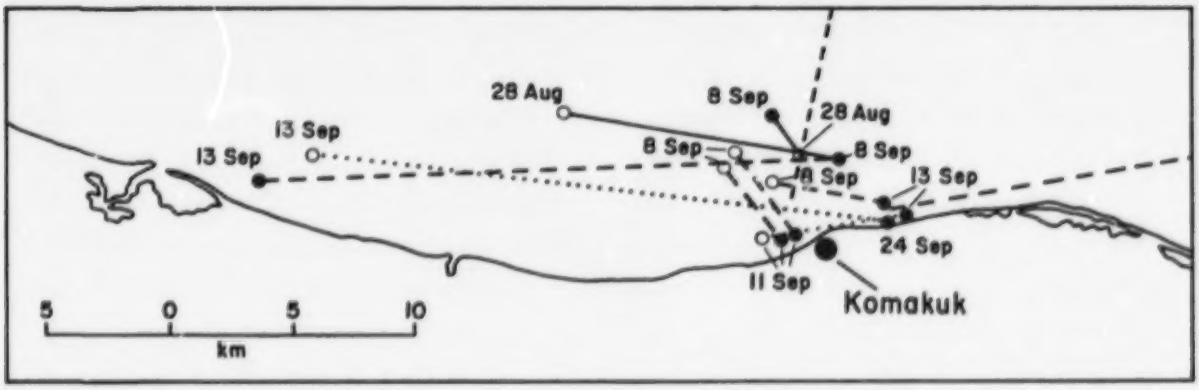


Figure 42. Inter-day resightings in the Komakuk Zone, 1985. Open circles indicate locations of the original photographs; closed circles indicate resightings. (Source: Richardson et al. 1987b).

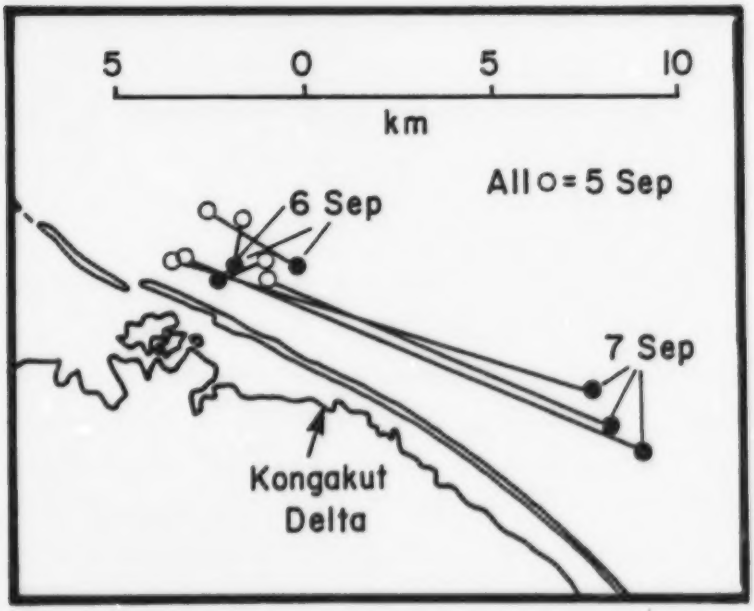


Figure 43. The inter-day resightings in the Eastern Alaska Zone, 1986. Open circles indicate the locations of the original photographs; closed circles indicate the resightings. (Source: Richardson et al. 1987b).

we obtained grade A and B photographs of less than half (19) of the 45-50 whales estimated to be present on 8 September. Thus, it is possible that some of the 32 whales photographed in the two groups on 28 August were present, but not photographed on 8 September. We obtained re-identifiable photographs of 18 whales at the 13 September resighting location east of Komakuk, and 19 whales at the resighting location west of Komakuk. Overall, 17 recognizable individuals photographed on 8 September were not resighted in either 13 September location.

Eastern Alaska

In 1986, six subadult (mean length 11.0 m, range 10.3-12.1 m) bowheads were photographed on 5 September. Three of these whales were rephotographed on 6 September and three were rephotographed on 7 September (Fig. 43). In both cases (one- and two-day resighting intervals) the resighted whales were rephotographed together, short distances from the original sighting area. Interestingly, these whales remained together despite having been displaced several kilometres by boat disturbance (zooplankton sampling) after the first photographs were taken on 5 September. They apparently returned to their original feeding location after that disturbance and were rephotographed on 6 September, when they were subjected to additional boat disturbance (see Thomson and Richardson 1987, p. 475, and Griffiths et al. 1987, p. 142 for details).

On 5 September we obtained re-identifiable photographs of 20 different whales. Three of these were resighted on 6 September when re-identifiable photographs of 14 whales were obtained. Thus, 17 recognizable whales photographed on 5 September were not resighted on 6 September. Re-identifiable photographs of 12 whales were obtained on 7 September, including the three that were resighted. None of the other 17 recognizable whales photographed on 5 September were resighted on 7 September.

Conclusions

The inter-day resighting data concerning seasonal site fidelity are summarized in Table 14 for the different study zones we have examined. These data suggest that seasonal site fidelity within zones is very high. In years and zones with moderate sized samples (four or more resightings in zone), seasonal site fidelity ranged from 88 to 100%. Minimum rates of movement calculated for these years and zones were lowest in the Komakuk Zone (1.3 and 1.9 km/day in 1985 and 1986) and highest in the King Point Zone (5.8 km/day). The overall average (including years and zones with small samples) was 5.9 km/day (n = 96).

Table 14. Summary of seasonal site fidelity and rates of movement of whales re-identified on different days.

Study Zone	Year	Seasonal Site Fidelity (%)	Sample Size[a]	Minimum Daily Rate of Movement (km/day)[b]	Resighted Whale Length (m)	
					Range	Mean
NC Amundsen	1985	0	1	25.6	-	13.2
Franklin Bay	1984	100	4	2.8	13.7-14.8	14.1
Franklin Bay	1985	100	15	4.3	11.0-14.4	13.3
King Point	1984	50	2	29.2	8.6-11.8	10.2
King Point	1985	92	37[c]	5.8	7.7-13.1	10.9
Interface	1986	0	1	6.6	-	10.8
Herschel Is.	1982	88	16	5.4	11.0-15.4	13.1
Herschel Is.	1984	0	1	57.0	-	8.6
Herschel Is.	1985	0	1	21.0	-	9.8
Komakuk	1985	100	8	1.3	8.9-13.7	11.8
Komakuk	1986	100	4	1.9	9.1-10.1	9.4
E Alaska	1986	100	6	4.4	10.3-12.1	11.0

[a] Number of within-year resightings of whales first photographed in this zone. Excludes resightings occurring on or after 15 September, which are presumed to include a considerable proportion of autumn migrants.

[b] Calculated by dividing the sum of minimum distances travelled in each inter-day resighting by the sum of the number of days between sightings.

[c] Only 36 length measurements were available.

These data suggest that in a given year whales in a zone subjected to tanker traffic will be repeatedly disturbed. Whales summering in zones remote from tanker traffic (e.g., Franklin Bay) probably will not be disturbed at all during the summer season, but may encounter tankers during the autumn migration.

The data concerning associations of individuals within groups indicate that the composition of groups of bowheads within study zones is very fluid. Although over some brief (1, 2 or 3 day) resighting intervals whales were photographed together on two days, more often they were photographed apart on one day and together on another, and this was especially the case for longer (up to 19 days) resighting intervals. Thus, frequent changes in the make up of bowhead associations appears to be normal in areas that may be subjected to disturbance from tanker traffic (e.g., King Point, Herschel Island, Komakuk and Eastern Alaska Zones) as well as in areas remote from potential disturbance (Franklin Bay Zone).

7. BETWEEN-YEAR SITE FIDELITY

All relevant photographic comparisons between the newly received Cascadia and NMFS Grade A photographs (158) and the existing LGL database (1422+ Grade A individuals) have been made. The new resightings are described below.

New Resightings

We found 12 new inter-year resightings as a result of comparing our photo collection with the newly acquired NMFS and Cascadia photos (Table 15). Fully two-thirds of these resightings involved whales photographed by LGL in the years 1981-85 that were rephotographed by Cascadia during late August and early September 1986 in an area north and west of Cape Bathurst (Tuktoyaktuk Peninsula Shelf Zone). These whales were originally photographed in a wide variety of locations, ranging from Komakuk in the western portion of the bowhead's summering grounds to Herschel Island, the Yukon Coast, Franklin Bay and Amundsen Gulf (Fig. 44).

The other inter-year resightings included whales that were present in each of two years in the Franklin Bay area (initially Offshore Bathurst Peninsula Zone; resighted Cape Parry Zone) and the Yukon Coast area (King Point Zone-Herschel Island Zone; King Point Zone-Komakuk Zone; and Komakuk Zone-Herschel Island Zone). Three of the 12 new inter-year resightings were of whales that had already been resighted in different years. Thus, we have photographed three of these whales in three different years (one in 1982, 1985 and 1986; two in 1984, 1985 and 1986, Table 15).

Between-Year Study Zone Fidelity

In this section we examine the resighting histories of 42 whales that were photographed in more than one summer or autumn. Most of these whales were photographed in two years, but four were photographed in three different years. We will determine how often resighted whales photographed in one area are rephotographed in the same areas in later years. (Six additional inter-year resightings between our summer-fall photographs and NMFS spring photographs taken near Barrow, Alaska, are not considered here.)

Table 15. Inter-year resightings of bowheads resulting from recent inter-study comparisons.

Source of Photos	Year	First Photographed				Resighting				Whale Length (m)	Year Measured
		Date	Loc'n[a]	Latitude	Longitude	Date	Loc'n	Latitude	Longitude		
LGL-CRC	1981-86	24 Jul	NWA	~71°13'N	124°47'W	31 Aug	TPS	70°44'N	130°51'W	14.1	1981
LGL-CRC	"	1 Aug	NCA	~71°18'N	121°48'W	31 Aug	TPS	70°43'N	129°43'W	13.6	1981
LGL-LGL-CRC	(1982-85)-1986[b]	5 Sep	HI	69°39'N	138°02'W	30 Aug	HI	69°40'N	138°33'W	12.8	1982
						1 Aug	TPS	70°42'N	128°34'W		
LGL-CRC	1982-86	17 Aug	FB	70°12'N	126°30'W	1 Sep	TPS	70°48'N	129°33'W	12.3	1986
NMFS-LGL	1984-85	17 Aug	OBP	70°45'N	128°05'W	24 Aug	CP	70°00'N	125°55'W	12.3	1985
LGL-LGL-CRC	(1984-85)-1986	16 Aug	I	69°29'N	136°48'W	13 Sep	K	69°38'N	140°40'W	11.8	1984
						25 Aug	HI	69°39'N	139°09'W		
LGL-LGL-CRC	"	17 Aug	HI	69°39'N	139°11'W	13 Sep	K	69°37'N	140°38'W	12.3	1984
						1 Sep	TPS	70°48'N	129°32'W		
LGL-CRC	1984-86	18 Aug	KP	69°09'N	138°03'W	25 Aug	HI	69°37'N	139°17'W	10.7	1984
LGL-CRC	"	1 Sep	FB	69°58'N	126°17'W	31 Aug	TPS	70°45'N	130°51'W	12.6	1984
LGL-CRC	1985-86	29 Sep[c]	EA	70°23'N	143°03'W	1 Sep	TPS	70°48'N	129°32'W	13.8	1985
CRC-LGL	"	25 Aug	KP	69°10'N	138°08'W	5 Sep[d]	K	69°50'N	141°50'W	10.5	1986
LGL-CRC	"	30 Aug	KP	69°05'N	137°35'W	31 Aug	TPS	70°42'N	130°53'W	9.3	1985

[a] NWA = NW Amundsen, NCA = NC Amundsen, HI = Herschel Island, FB = Franklin Bay, OBP = Offshore Bathurst Peninsula, I = Interface, KP = King Point, EA = Eastern Alaska, AK, TPS = Tuktoyaktuk Peninsula Shelf, CP = Cape Parry, K = Komakuk, see Figures 6-8 for locations of those study blocks.

[b] Parentheses surround resightings recognized prior this study.

[c] This bowhead was also photographed on 3 August 1985 at 70°47'N, 122°41'W (Richardson et al. 1986, p. 190).

[d] This bowhead was also photographed on 6 September 1986 at 69°50'N, 141°51'W (Richardson et al. 1987b, p. 322).

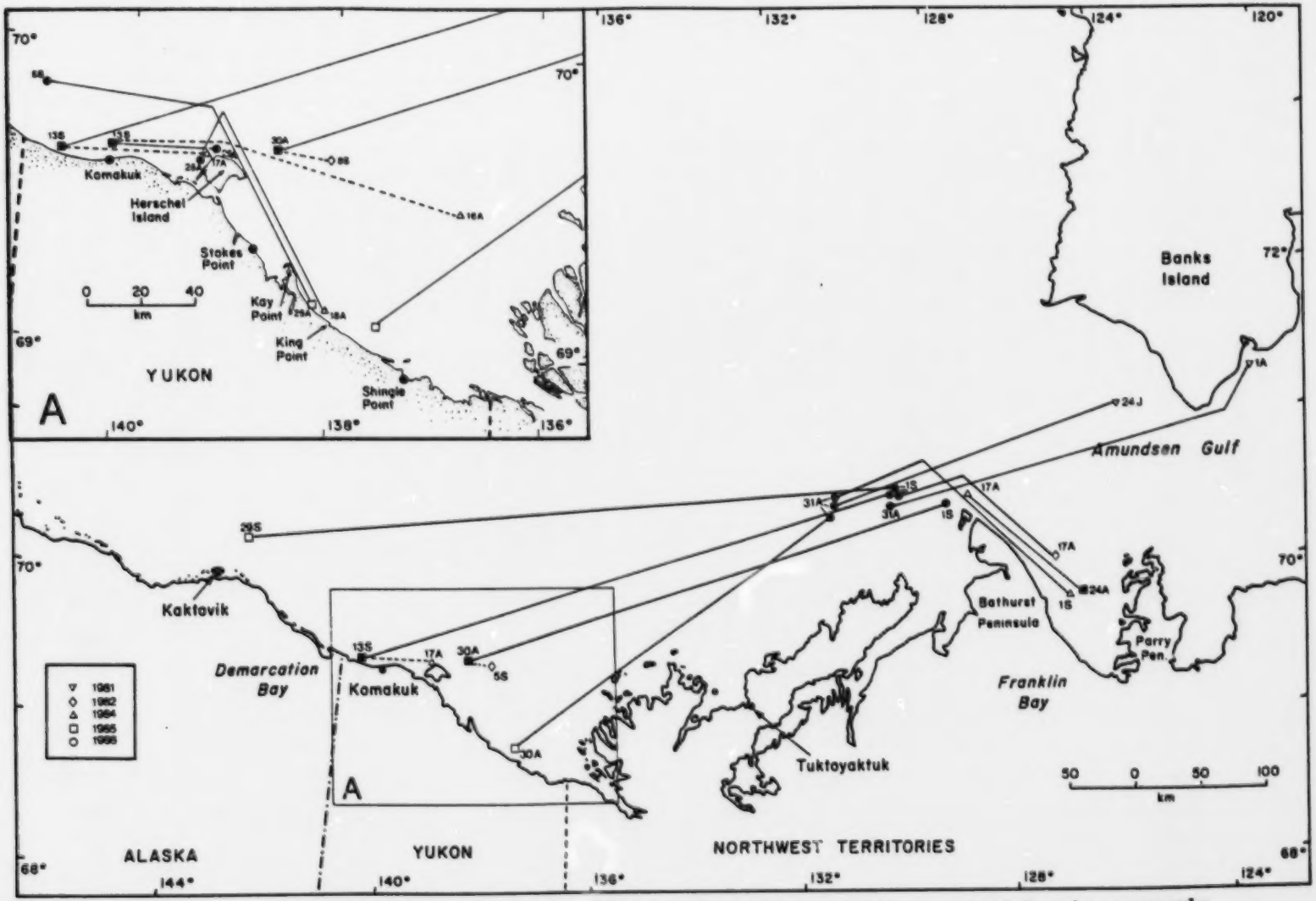


Figure 44. New inter-year resightings of bowheads. Resightings wholly contained by the rectangle around the Yukon coast are shown in inset A. Open symbols show locations where whales were first photographed, closed symbols represent resightings. Dashed lines indicate inter-year resightings of these same whales recognized prior to this study.

Amundsen Gulf

Seven bowheads photographed in the NC and NW Amundsen Gulf Zones in 1981 and 1985 were rephotographed in later years (Table 16). All of the resightings occurred outside of the original sighting zones. The original sightings were all very early in the open water season (24 July-3 August). The absence of resightings in this area may be partly attributable to the fact that almost all potential opportunities for resightings were later in the summer or fall, when these whales may be elsewhere. Also, there was relatively little photography effort in Amundsen Gulf, reducing opportunities for resightings there. All seven resighted whales were adults, over 13 m in length. One of them had a calf in 1986 when it was photographed in the Tuktoyaktuk Peninsula Shelf Zone, but not when it was originally photographed in 1981.

No whales that were first photographed elsewhere were resighted in later years in Amundsen Gulf.

Table 16. Inter-year resightings originating in the NW and NC Amundsen Gulf Zones.

Year	Original Sighting		Resighting(s)		Net Distance Between Sightings (km)	Whale Length (m)	Year Measured
	Date	Zone[a]	Date	Zone[a]			
1981-82	1 Aug	NCA	23 Aug	DS	570	14.2	1982
1981-85	1 Aug	NCA	21 Aug	CP	179	13.4	1985
"	1 Aug	NCA	21, 27 Aug	FB	232	13.2	1985
1981-86	24 Jul	NWA	31 Aug	TPS	228	14.1	1981
"	24 Jul	NWA	27 Sep	K*	589	13.6	1981
"	1 Aug	NCA	31 Aug	TPS[b]	304	13.6	1981
1985-86	3 Aug[c]	NCA	1 Sep	TPS	253	13.8	1985

[a] NCA = NC Amundsen, NWA = NW Amundsen, DS = Delta Shelfbreak, CP = Cape Parry, FB = Franklin Bay, TPS = Tuktoyaktuk Peninsula Shelf, K = Komakuk.
[b] Photographed with calf in 1986.
[c] This whale was also photographed on 29 September 1985 in the Eastern Alaska Zone (70°23'N, 143°03'W). See Table 8 for details.
* After 15 September—probable fall migrant.

Franklin Bay, Cape Parry and Offshore Bathurst Peninsula Zones

Ten whales photographed in these contiguous zones in 1982, 1984 and 1985 were rephotographed in another year (Table 17). If we eliminate the two probable fall migrants that were rephotographed in the Komakuk Zone after 15 September, then 5 of 8 (62%) of the whales were resighted in Franklin Bay. These five whales were all originally photographed in Franklin Bay except for one that was photographed about 8 km north of Franklin Bay in the Offshore Bathurst Peninsula Zone in 1984. Two whales originally photographed in Franklin Bay (1982 and 1984) were photographed in the Tuktoyaktuk Peninsula Shelf Zone in late August and early September 1986. Another whale photographed in Franklin Bay on 1 September 1984 was rephotographed in the King Point Zone on 6 September 1985.

Table 17. Inter-year resightings originating in the Franklin Bay, Cape Parry and Offshore Bathurst Peninsula Zones.

Year	Original Sighting		Resighting(s)		Net Distance Between Sightings (km)	Whale Length (m)	Year Measured
	Date	Zone[a]	Date	Zone[a]			
1982-85	17 Aug	FB	27 Aug	FB	78	13.4	1985
1982-86	17 Aug	FB	1 Sep	TPS	150	12.3	1986
1984-85	17 Aug	OBP	24 Aug	FB	117	12.3	1985
"	23 Aug, 1 Sep	FB	25 Aug	FB	26	14.1	1985
"	23 Aug, 6 Sep	FB	22 Aug	FB	83	14.1	1985
"	1 Sep	FB	6 Sep[b]	KP	498	13.5	1985
"	6 Sep	FB	21, 25 Aug	FB	80	13.1	1985
1984-86	23 Aug, 6 Sep	FB	19 Sep	K*	482	13.7	1984
"	1 Sep	FB	31 Aug	TPS	222	12.6	1984
1985-86	21 Aug	CP	27 Sep	K*	573	15.2	1986

[a] FB = Franklin Bay, OBP = Offshore Bathurst Peninsula, CP = Cape Parry, TPS = Tuktoyaktuk Peninsula Shelf, K = Komakuk.

[b] This whale was also photographed in the Komakuk Zone on 22 September 1985; see Table 10 for details.

* After 15 September—probable fall migrant.

Excluding probable fall migrants, 62% of the resighted whales that were originally photographed in the Franklin Bay region were rephotographed there in later years. Four of these resightings were one year apart (1984-85) and one was three years apart (1982-85). The two whales rephotographed in the Tuktoyaktuk Peninsula Shelf Zone in 1986 had two and four year resighting intervals. The single whale rephotographed in the King Point Zone had a one year (1984-85) resighting interval. The whales involved in these resightings ranged in length from 12.3 to 15.2 m and averaged 13.4 m.

There were four additional whales that were resighted in [illegible] Franklin Bay or Cape Parry zones after being photographed in an earlier year elsewhere (Tables 16, 18): two from NC Amundsen Gulf (1981-85) and two from Herschel Island (1982-84 and 1982-85). Given the large number of potentially re-identifiable whales photographed off the Yukon coast, the low number of exchanges with that area is noteworthy.

Tuktoyaktuk Peninsula Shelf

No whales that were first photographed here were rephotographed in a later year. However, eight whales first photographed elsewhere were rephotographed in later years off the Tuktoyaktuk Peninsula. These included five from farther east, in Amundsen Gulf or Franklin Bay (Tables 16, 17), and three from farther west near King Point or Herschel island (Tables 18, 19). Interestingly, all of these sightings and resightings were before 15 September, suggesting that whales that summer off the Tuktoyaktuk Peninsula may have summered either farther east or farther west in earlier years. Those that had previously summered farther east were moderate to large sized whales (12.3-14.1 m). Those that had previously summered farther west were small or moderate sized (9.3, 12.3, 12.8 m).

Herschel Island

Seven whales originally photographed in the Herschel Island Zone in 1982 and 1984 were photographed in two years and two were photographed in three years. Since the second year of one of these three year resightings also occurred in the Herschel Island Zone there are 12 different resightings that

originated in this zone (Table 18). Even excluding two probable fall migrants resighted after 15 September in the Komakuk and Central Alaska Zones, only 10% (1 of 10) of the resightings occurred in the Herschel Island Zone. The single same-zone resighting occurred over an interval of three years (1982-85) and involved a 12.8 m whale (in 1982) that was also resighted in the Tuktoyaktuk Peninsula Shelf Zone in 1986. Four of the remaining seven resightings occurred in the nearby Interface (1982-84), King Point (1982-84 and 1982-85) and Komakuk (1984-85) Zones, and were an average of 97 km from the original sighting locations. The three other resightings occurred in Franklin Bay (1982-84 and 1982-85) and the Tuktoyaktuk Peninsula Shelf Zone (1984-86). The Herschel Island resightings involved whales ranging from 11.8 to 15.4 m and averaging 13.6 m. One of these whales (12.5 m) was photographed with a calf in

Table 18. Inter-year resightings originating in the Herschel Island Zone.

Year	Original Sighting		Resighting(s)		Net Distance Between Sightings (km)	Whale Length (m)	Year Measured
	Date	Zone[a]	Date	Zone[a]			
1982-84	16 Aug	HI[b]	30 Aug	I	123	12.6	1984
"	24 Aug	HI[c]	1 Sep	FB	504	12.5	1984
"	4 Sep	HI	30 Aug, 2 Sep	KP	108	11.8	1984
1982-85	16 Aug	HI	6 Sep	KP	103	12.5	1985
"	5 Sep	HI	21, 25 Aug	FB	522	14.4	1985
1982-85-1986	5 Sep	HI	30 Aug	HI	21	12.8	1982
			1 Sep	TPS	394[d]		
1982-86	16, 18 Aug	HI	26 Sep	K*	80	12.7	1986
	18, 24 Aug	HI	19 Sep	CA*	326	15.4	1986
1984-85-1986	17 Aug	HI	13 Sep	K	54	12.3	1984
			1 Sep	TPS	439[d]		

[a] HI = Herschel Island, I = Interface, FB = Franklin Bay, KP = King Point, TPS = Tuktoyaktuk Peninsula Shelf, K = Komakuk, CA = Central Alaska.

[b] This whale was also photographed on 4 September 1982 in the Offshore Yukon Zone (70°36'N, 138°52'W). See Table 11 for details.

[c] Photographed with a calf in 1982.

[d] Distance from previous resighting.

* After 15 September—probable fall migrant.

1982, but no calf was present when it was rephotographed in 1984 in Franklin Bay.

Besides the nine whales first photographed near Herschel Island and rephotographed in later years (mainly elsewhere), three whales first photographed elsewhere in 1984 and 1985 (all in the nearby Komakuk, King Point, and Interface Zones) were later resighted near Herschel Island in 1986 (Table 19).

King Point and Interface Zones

Eleven whales photographed in the King Point and Interface Zones in 1982, 1984 and 1985 were rephotographed in another year. Two of these whales were photographed in three years. In all, 13 inter-year resightings originated in these zones (Table 19). Excluding two probable fall migrants that were rephotographed in the Komakuk Zone after 15 September, only 18% (2 of 11) of these resightings occurred in the King Point or Interface Zones (1982-85 and 1984-85). With the exception of one resighting in the Tuktoyaktuk Peninsula Shelf Zone some 312 km distant (1985-86), all summer resightings occurred in the western Canadian or eastern Alaskan Beaufort within 150 km of the original sighting locations: the aforementioned two within the King Point zone, three in Eastern Alaska (3--1985-86), two near Komakuk (1--1984-85 and 1--1984-86), and three near Herschel Island (2--1984-86 and 1--1985-86). These whales were much smaller (mean 10.4 m, range 9.0-12.5 m) than the resighted whales photographed in the Franklin Bay and Herschel Island Zones (mean lengths 13.4 and 13.6 m, respectively).

Six additional whales were resighted in the King Point and Interface Zones after being photographed in an earlier year elsewhere (Tables 17, 18, 20). One of these was originally sighted about 500 km to the east in Franklin Bay (1984-85). The remaining five were from the nearby Herschel Island (2--1982-84, 1--1982-85) and Komakuk (1984-85 and 1985-86) Zones.

Table 19. Inter-year resightings originating in the King Point and Interface Zones.

Year	Original Sighting Date	Original Sighting Zone[a]	Resighting(s) Date	Resighting(s) Zone[a]	Net Distance Between Sightings (km)	Whale Length (m)	Year Measured
1982-85	24 Aug	KP	13 Sep	KP	16	10.4	1985
1984-85	16 Aug	KP	27 Aug	KP	34	9.0	1985
1984-85-1986	16 Aug	I	13 Sep	K	150	12.5	1985
			25 Aug	HI	40[b]		
"	24 Aug	KP	26 Sep	K*	132	9.2	1985
			5, 6, 14 Sep	K	43[b]		
1984-86	18 Aug	KP	25 Aug	HI	103	10.7	1984
1985-86	18 Aug	KP	5, 7 Sep	EA	166	10.7	1985
"	25 Aug	KP	5 Sep	EA	143	10.5	1986
"	30 Aug	KP	31 Aug	TPS	312	9.3	1985
"	6 Sep	KP	19 Sep	K*	119	10.5	1985
"	13 Sep	KP	3 Sep	HI	64	10.6	1985
"	13 Sep	KP	5 Sep	EA	145	10.9	1985

[a] KP = King Point, I = Interface, K = Komakuk, HI = Herschel Island, EA = Eastern Alaska, TPS = Tuktoyaktuk Peninsula Shelf.
[b] Distance from previous sighting.
* After 15 September—probable fall migrants.

Komakuk

The five inter-year resightings that originated in the Komakuk Zone are shown in Table 20. In addition to these five resightings, three three-year resightings involving whales that were at Komakuk in the middle year are shown in Tables 18 and 19. In total eight inter-year resightings originated at Komakuk. Excluding three resightings that involved whales photographed or rephotographed after 15 September, some of which may have been fall migrants, only 20% (1 of 5) of these whales were resighted in the Komakuk Zone (1985-86). However, three of the four remaining resightings involved whales that were photographed in the nearby Interface (1985-86), King Point (1984-85) and Herschel Island (1985-86) Zones. This latter Herschel Island whale was also photographed in the Interface Zone in 1984. One whale first photographed at

Table 20. Inter-year resightings originating in the Komakuk Zone.

Year	Original Sighting Date	Original Sighting Zone[a]	Resighting(s) Date	Resighting(s) Zone[a]	Net Distance Between Sightings (km)	Whale Length (m)	Year Measured
1984-85	18 Aug	K	14 Sep	KP	119	8.1	1984
"	14 Sep	K	22 Sep	K*	70	9.7	1984
1985-86	28 Aug, 8 Sep	K	27 Sep	K*	54	13.7	1985
"	8 Sep	K	26 Aug[b]	I	124	10.6	1985
"	11, 13 Sep	K	5, 19 Sep	K	27	10.4	1985

[a] K = Komakuk, KP = King Point, I = Interface.
[b] Also photographed on 15 September 1986 in the Komakuk Zone (69°39'N, 140°29'W). See Table 10 for details.
* After 15 September—probable fall migrants.

Herschel Island in 1984 and then at Komakuk in 1985 was rephotographed about 440 km to the NE in the Tuktoyaktuk Peninsula Shelf Zone (in 1986). The resighted Komakuk whales were small, averaging 10.8 m and ranging from 8.1 to 13.7 m.

Besides the whales first photographed near Komakuk and later photographed elsewhere, there were eight resightings at Komakuk of whales photographed elsewhere in earlier years. Of these, six were rephotographed at Komakuk after 15 September and may have been migrating when rephotographed. When first photographed in earlier years, they were in the NW Amundsen, Cape Parry, Franklin Bay, King Point (2) and Herschel Island zones (Tables 16-19). Only two whales were first photographed elsewhere (Interface or Herschel Island) and then rephotographed before 16 September in a later year near Komakuk.

Conclusions

Site fidelity was highest in the Franklin Bay region. Sixty-two percent (5 of 8) of the resighted whales that were originally photographed in the Franklin Bay and extreme southern Offshore Bathurst Peninsula Zones were rephotographed in the Franklin Bay zone in a later year. Observed inter-year site fidelity in the other zones discussed above was much lower, ranging from

0% in the Amundsen Gulf Zones (where there were few opportunities for between-year resightings) to 20% in the Komakuk Zone.

The moderate site fidelity demonstrated by the large (mean length 13.4 m) whales that summer in the Franklin Bay region, remote from Amauligak and its associated shipping lanes, suggests that these whales will tend to remain unaffected by Amauligak production and shipping activities during the summer. The large (mean length 13.0 m) whales that were photographed in the Herschel Island Zone in some summers (1982, 1984 and 1985) tended to be resighted both east and west of the Herschel Island Zone. Some of these whales (those that sometimes summer in the Franklin Bay and Tuktoyaktuk Peninsula Shelf Zones) would be remote from Amauligak activities in some years.

The small whales originally photographed in the King Point-Interface and Komakuk Zones (10.4 and 10.8 m, respectively) would be potentially exposed to Amauligak shipping in most years since they tended to be resighted in zones located along the proposed shipping lanes (e.g., Interface, King Point, Herschel Island, Komakuk and Eastern Alaska Zones).

8. KNOWN EFFECTS OF SHIP TRAFFIC

The short-term reactions of bowhead whales to various industrial activities have been studied for several years in the Beaufort Sea. Activities studied have included mobile and stationary marine noise sources, seismic exploration, and aircraft of various types. The observed reactions to vessel traffic are discussed here.

Observed Reactions

In the Canadian Beaufort Sea, oil industry personnel have reported bowheads within a few hundred meters of various vessels; sometimes the whales dove, possibly in response to the vessel (Fraker 1978; Fraker and Fraker 1979, 1981). More detailed information about reactions to ships and boats operating in open water was obtained by Richardson et al. (1985a,b), who observed seven such incidents from an aircraft circling high above. Obvious avoidance responses usually began when a vessel approached to within 1.5-4 km. However, a few whales may have begun reacting when the vessel was as much as 5-7 km away and, in contrast, a few others did not appear to react until the vessel was <1 km away. The initial reaction was usually to try to outswim the vessel. When an overtaking vessel approached within a few hundred meters, the whales often changed course and moved perpendicularly away from the boat's track. The whales ceased fleeing after the vessels were a few kilometers past. In one example, a cow-calf pair began swimming rapidly when a directly approaching 13 m diesel-powered vessel was over 3.4 km away (Richardson et al. 1985b).

The levels of underwater noise that apparently elicited these escape reactions were not very high. In one disturbance test, received noise levels 4 and 1.5 km from the approaching vessel were only about 84 and 91 dB re 1 µPa in the 1/3-octave band of strongest noise. These values were only about 6 and 13 dB above the background noise level in that band (Miles et al. 1987).

Fleeing bowheads typically swam faster than observed at other times, and exhibited shorter-than-average surface times, fewer respirations per surfacing, and reduced dive durations. Although the escape reactions of bowheads were most conspicuous when a vessel headed directly toward them,

reduced surface times and fewer respirations per surfacing were evident when a crew boat's engines began idling 3-4 km away after a quiet period (Richardson et al. 1985a,b).

Similar observations were obtained in the eastern Alaskan Beaufort Sea in a study by Koski and Johnson (1987) during early autumn 1986. Whales were exposed to ship traffic during four observation sessions. Strong responses were observed in three cases; subtle responses were observed during the fourth case.

On 5 and 11 September, supply ships underway passed by the edges of groups of whales at distances of 1-3 km. All of the whales near the paths of the ships exhibited strong responses including direct movements away from the ship track. On 5 September, one whale moved about 6 km from the track. On 11 September, three individuals moved to points at least 6 km from the track of the passing ship; a fourth whale about 6 km away from the track exhibited no directional movement. The moving whales travelled at rates of 3.2 to 7.2 km/h. Whale reactions ceased when the ship was just past the whales and heading away even though it was still closer to the whales than when the initial reactions began. The direction of movement relative to the whales seemed important.

On 5 September, it was noteworthy that the whale that moved rapidly away from the ship apparently returned to the coastal feeding area soon after the ship passed. In fact, one of the whales photographed on 5 September was present again on 6 September; photo identification data showed that it and at least two more of the feeding whales exposed to the ship on 5 September were still present in the same general area 9-14 days later (Richardson et al. 1987b).

The third session in September 1986 did not involve the close approach of rapidly travelling vessels. Instead, a cow-calf pair exhibited strong responses (behavior changes) in the presence of two ships approaching from different directions. The supply ship Canmar Supplier III approached from the east and passed about 15 km south of the whales. The icebreaker Robert Lemeur approached (in open water) from the west to within about 20 km of the cow-calf. The strong responses by the whales were surprising since the ships did

not approach closely. Perhaps the responses were related to the fact that the whales were between two ships approaching from different directions.

In the fourth session, a migrating whale was 27-31 km from an active drillship and 28 km from a non-operating, but travelling, seismic ship. No whale behavioral responses could be attributed to the ships.

For other areas and seasons, very little information about reactions of bowheads to vessels is available. Kibal'chich et al. (1986), while observing bowheads from a vessel in the extreme northern Bering Sea during late autumn, noted that the whales moved away if the vessel approached within 400-600 m. New ice was forming at the time. Since the observations were from the vessel, whales reacting at longer ranges probably would not have been noticed. In the eastern Canadian arctic, bowheads have been reported to be very sensitive to motor boats (Degerbøl and Freuchen 1935). Recently, the track and speed of a bowhead fleeing from an outboard-powered boat were determined by theodolite (Finley et al. 1986). The animal moved very rapidly (for a bowhead) as the boat approached: 7.7 km/h during one dive and 10.3 km/h during the next; during the latter dive the whale traveled 1.8 km underwater. This strong reaction to outboard motor noise occurred despite the fact that eastern arctic bowheads are not hunted.

In general, bowheads react strongly and rather consistently to approaching vessels of a wide variety of types and sizes. Bowheads interrupt their normal behavior and swim rapidly away. Surfacing, respiration and diving cycles are affected during this time. The escape response usually subsides by the time that the vessel has moved a few kilometers away. Following single disturbance incidents, at least some bowheads return to their original locations.

Implications

The available data clearly indicate that bowheads respond to approaching ships by moving out of the way. There are few data on the distance at which whales first begin to respond to approaching ships. This distance is likely to be variable depending on a complex of factors including noise level of the

ship, speed of the ship, propagation loss characteristics, water depth, proximity to shore, age of the animals, and previous experience with ship traffic. Overt responses can begin at ranges of 1 to >7 km from an approaching vessel. In spite of this complexity, it seems that whales are relatively consistent in moving about 6 km to the side of the track of a passing ship. The reactions of the whales seem to diminish soon after the ship starts to move away from animals. This is in spite of the fact that received noise levels are likely still very high since the ship is near its closest-point-of-approach (CPA) to the whales.

It is important to evaluate these escape responses of bowheads in the context of their normal, undisturbed movements. Whales very close to the track of an approaching vessel would be expected to move up to 6 km away from the track. These movements are conducted at rates of anywhere from 3-10 km/h over periods of ½ hour to 2 hours. In the absence of ship traffic, whales move an average of about 2 km/h for periods longer than one hour (see Section 5 of this report). Thus, the average whale moves about 6 km in three hours, even if no ships are present.

The similarity of the distances moved to avoid ships and distances normally moved, mean that extreme care is needed when studying and interpreting the short-term responses of bowheads to tanker traffic. Responses must be measured as the ship is actually approaching the whales. It is not possible to arrive at the scene an hour or two after the ship has passed and hope to reliably interpret the significance of observed distribution patterns.

Further discussion of the responses of bowheads to ship traffic will be found in Sections 9 and 10.

9. SEPARATION OF COW-CALF PAIRS

The Concern

At the March 1987 BEMP workshop, the working group discussing the potential effects of tankers identified the possibility that calves could become permanently separated from their mothers as a result of disturbance caused by the ships. This was a concern because cows and calves are often separated in the late summer and fall as females forage up to 1 km from the calf (Würsig et al. 1985). If an approaching ship masked communication between the mother and calf and then frightened them in different directions, it is conceivable that they would be unable to find each other subsequently. The likelihood of such separation is addressed here in a theoretical way using existing data.

It was demonstrated earlier (Sections 1 and 2) in this report that cow-calf-pairs will occur along potential tanker routes from Amauligak to the west. The numbers of calves can be quite high in some years but, in general, no major, repetitively used calf-rearing areas are known to occur along potential tanker routes. Areas with large numbers of calves were off Herschel Island in the late summer of 1982, the eastern Alaskan Beaufort Sea in 1982, and off the western Yukon coast and eastern Alaskan coasts in the autumn of 1986. In years such as these, significant numbers of calves would be exposed to underwater noise from the shuttle tanker traffic.

Ship Noise

In general, boats and ships create substantial amounts of noise that travels for long distances underwater (cf. Richardson et al. 1983). To evaluate potential effects of ships, it is necessary to know how much noise a ship generates and how far that noise travels. Noise levels from several ships operating in arctic waters have been measured in recent years (Finley et al. 1983, 1984; Greene 1985, 1987). Included in these studies were measurements of the icebreaking ore carrier/tanker MV Arctic. This ship could be the shuttle tanker used to carry crude oil from Amauligak to a larger tanker anchored off western Alaska.

C.R. Greene, Jr. (in Finley et al. 1983) measured received noise levels from the MV Arctic breaking ice at a distance of 463 m. He assumed spherical spreading loss and calculated a first approximation of the source levels of ship noise at 1 m. These levels are presented for various frequency bands in Table 21. The spectrum levels (i.e. bandwidth 1 Hz) are presented in Figures 45 and 46. These measurements were made when the MV Arctic was icebreaking fast ice in Admiralty Inlet. The ship travelled forward through the ice until it lost momentum; it then backed-up and rammed the ice again. The data demonstrate that the increased propeller cavitation associated with reversing thrust and going astern produced higher noise levels than did straight-ahead icebreaking. The going ahead levels for the MV Arctic were similar to source levels for the Class 3 icebreaker Robert Lemeur underway at 10-12 knots in the eastern Alaskan Beaufort Sea in September 1986 (Greene 1987; Miles et al. 1987).

The source noise levels for these vessels are quite high and they would be detectable at quite long ranges. In the following conceptual models we will use data from these vessels to determine the noise levels that cow-calf pairs would be exposed to. We have purposely chosen to use source levels that are at the high end of the range since this is the conservative approach in looking for potential effects.

Propagation Loss

The most detailed study of propagation loss in the Beaufort Sea was conducted by BBN Laboratories Inc. and LGL Limited for the U.S. Minerals Management Service in 1985 and 1986 (Miles et al. 1987). They measured and modelled sound transmission characteristics at six sites in the eastern Alaskan Beaufort Sea. Their easternmost site 'Belcher' (70°16'N, 141°47'W) was located in 55 m of water about 70 km ENE of Kaktovik, Alaska. This was the deepest and farthest offshore site studied and thus is most appropriate for evaluating noise from transiting tankers. In general, Miles et al. (1987) found that "sound attenuates less rapidly with increasing distance in the Beaufort Sea than in many other areas ... there is very efficient cylindrical spreading (10 log Range) of acoustic energy to ranges of 25 to 40 km ...". We

Table 21. Estimated source levels for MV Arctic operating in ice.

Frequency band (Hz)	dB//1 μPa-m	
	Going ahead[a]	Going astern[b]
10-500	183	190
100-500	179	185
200-500	177	180
10-1000	184	191
100-1000	181	186
200-1000	180	182
10-20	168	177
20-40	172	181
40-80	179	184
80-160	176	187
160-320	176	179
320-640	176	179
100-200	176	183
200-400	176	178
400-800	177	179
80-4000	181	185
800-4000	178	179
1600-4000	174	176
800-1600	176	176
1600-3200	173	175
320-16000	180	182
3200-16000	171	176
6400-16000	163	170
3200-6400	170	174
6400-12800	163	169

[a] Average of 8 samples.
[b] Average of 5 samples.

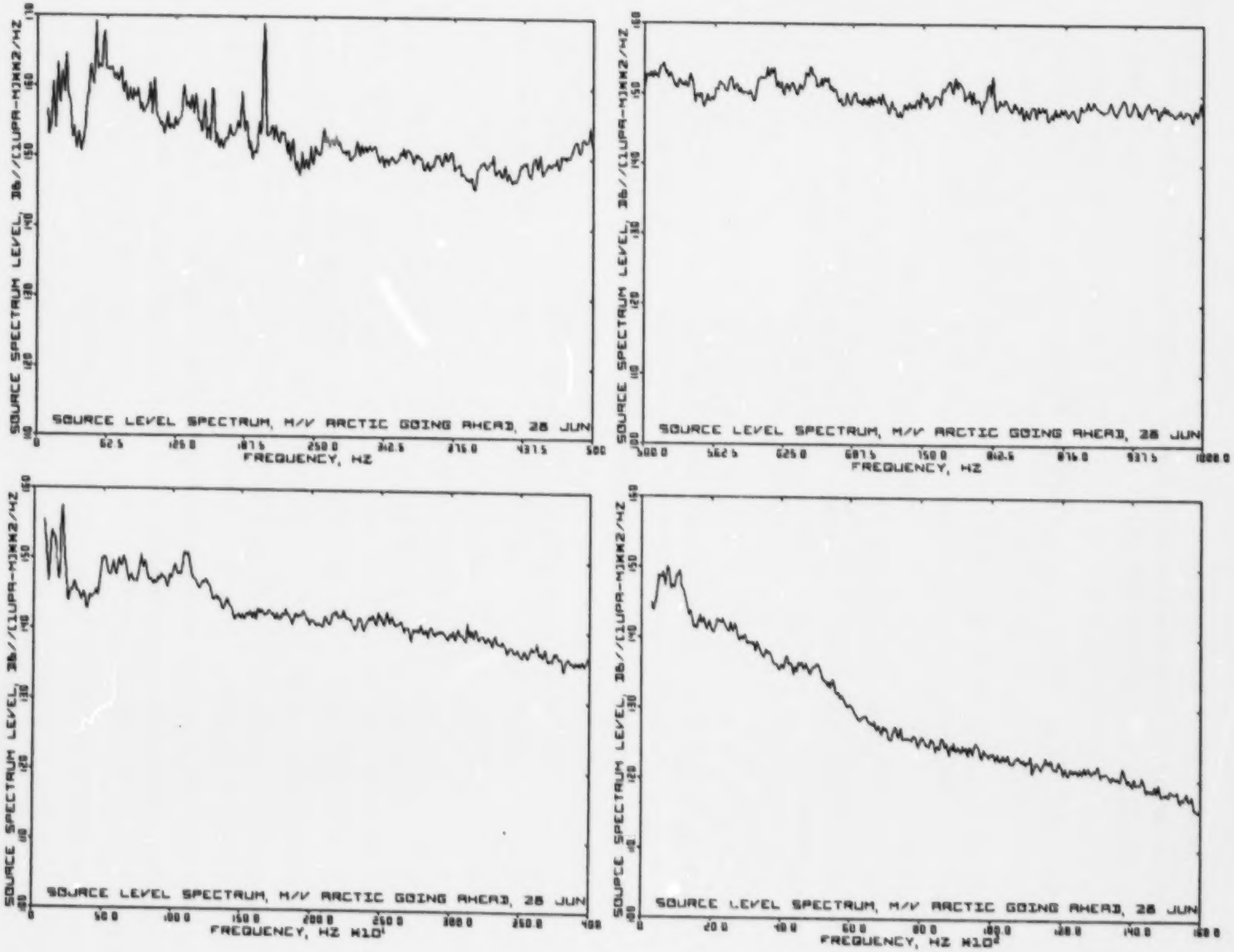

SOURCE SPECTRUM LEVEL, DB//(1UPA-M)KM2/HZ
SOURCE LEVEL SPECTRUM, M/V ARCTIC GOING AHEAD, 28 JUN
FREQUENCY, HZ
SOURCE SPECTRUM LEVEL, DB//(1UPA-M)KM2/HZ
SOURCE LEVEL SPECTRUM, M/V ARCTIC GOING AHEAD, 28 JUN
FREQUENCY, HZ
SOURCE SPECTRUM LEVEL, DB//(1UPA-M)KM2/HZ
SOURCE LEVEL SPECTRUM, M/V ARCTIC GOING AHEAD, 28 JUN
FREQUENCY, HZ X10¹
SOURCE SPECTRUM LEVEL, DB//(1UPA-M)KM2/HZ
SOURCE LEVEL SPECTRUM, M/V ARCTIC GOING AHEAD, 28 JUN
FREQUENCY, HZ X10²

Figure 45. Source level spectrum of the MV Arctic going ahead.

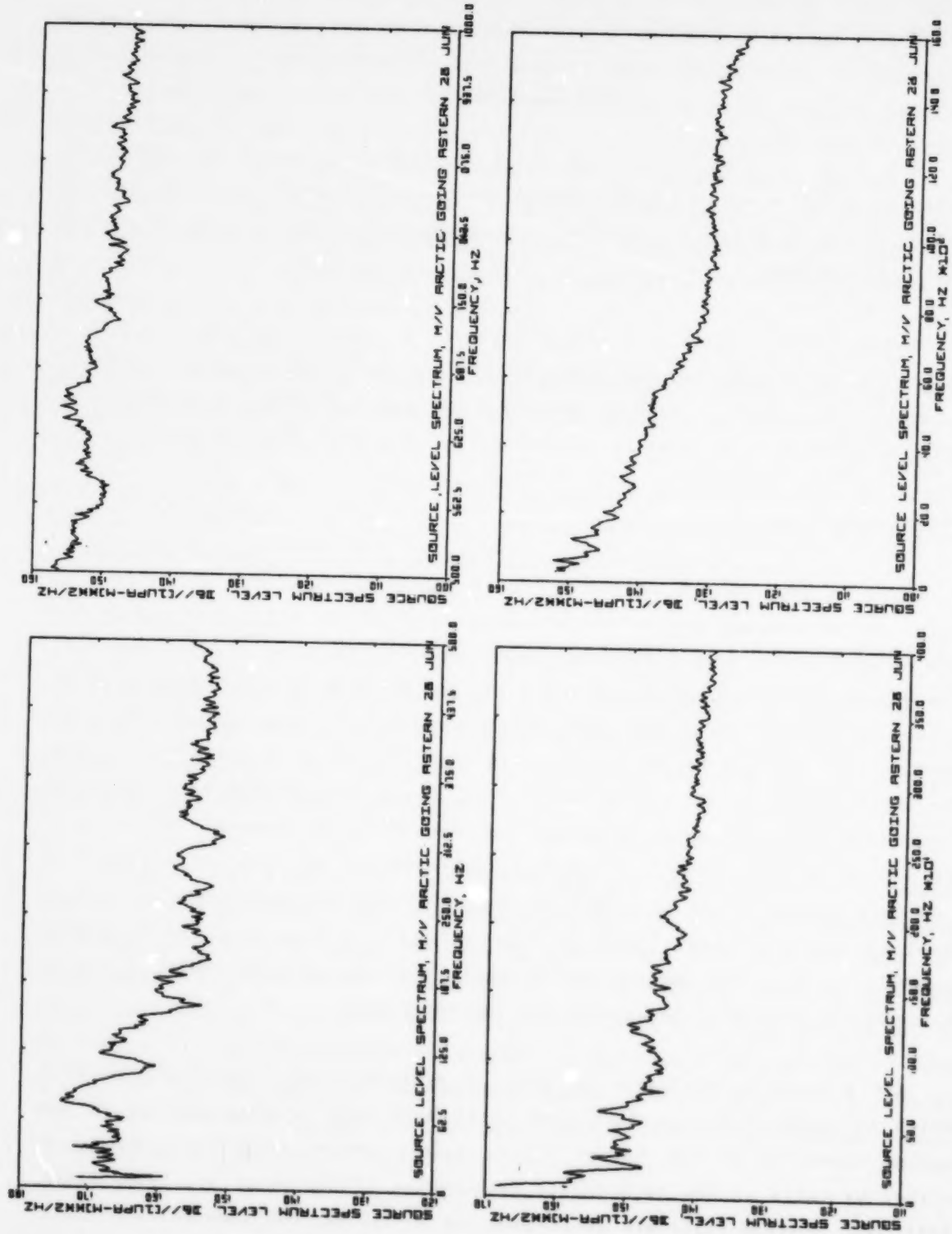

SOURCE LEVEL SPECTRUM, M/V ARCTIC GOING ASTERN 28 JUN
SOURCE SPECTRUM LEVEL, 36//(1UPA-M2MK2/HZ
FREQUENCY, HZ
FREQUENCY, HZ X10³

Figure 46. Source level spectrum of the MV Arctic going astern.

will use the specific data from the Belcher site in the conceptual models derived later in this chapter.

Zones of Influence

W.J. Richardson of LGL Limited did a detailed analysis of the conceptual basis for defining various zones of influence around industrial noise sources (see p. 42-63 of Miles et al. 1987). That analysis forms the basis of the present discussion.

Theoretically, noise can affect bowheads in several different ways and several zones of potential influence can be conceived. These zones are based on audibility, whale response, masking, and auditory damage, although the latter zone is so small that it is probably not relevant for ship noise.

Zone of Audibility

This is the largest of the zones of possible influence. The radius of audibility will depend partly on the source level of the ship noise and on its rate of attenuation with increasing range. However, the size of this zone will also depend on the ambient noise level and the minimum ratio of ship noise to ambient noise that can be detected. This ratio is often taken to be 0 dB, i.e. assuming that a sound can be detected provided that it is no less intense than the background noise at corresponding frequencies. However, in some circumstances sounds can be detected even when they are somewhat less intense than the background noise, i.e. at a signal-to-noise ratio slightly less than 0 dB (see Richardson et al. 1983 for review). Another consideration is the absolute hearing sensitivity of the animal. If the absolute detection threshold is above the ambient noise level, then the zone of audibility will be limited by detection threshold, not ambient noise.

Any attempt to estimate the zone of audibility of a sound to bowhead whales is hampered by the fact that there have been no measurements of the hearing threshold of any baleen whale. Baleen whales communicate with one another by calls at low to moderate frequencies (Thompson et al. 1979; Clark 1983). Most bowhead calls are at frequencies 50-500 Hz, but some calls contain

energy up to 5000 Hz (Ljungblad et al. 1982b; Clark and Johnson 1984; Würsig et al. 1985; Cummings and Holliday 1987). It seems safe to assume that whales are sensitive to the frequencies contained in their calls; there is behavioral evidence that some baleen whales detect and respond to calls from conspecifics many kilometers away (Watkins 1981; Tyack and Whitehead 1983). The structure of the hearing apparatus of baleen whales is appropriate for detection of low and moderate frequencies (Fleischer 1976; Norris and Leatherwood 1981). Malme et al. (1983) demonstrated that migrating gray whales could detect the presence of Orca (killer whale) sounds in a tape playback experiment when the signal-to-noise ratio was about 0 dB.

Payne and Webb (1971) pointed out that, at 20 Hz, detection range would be limited by background noise rather than auditory sensitivity even if auditory sensitivity were as much as 30 dB poorer than human auditory sensitivity at humans' most sensitive frequency. Thus, following Payne and Webb (1971) and Gales (1982a,b), we assume that ambient noise, not limited auditory sensitivity, sets the upper limit on the zone of audibility.

Zone of Responsiveness

The zone of responsiveness is defined by the distance at which bowheads overtly respond to approaching ships. Although internal physiological responses may occur at longer distances, the onset of overt responses is the only presently useful functional criterion.

Richardson in Miles et al. (1987) reviewed the available data on bowhead responses to stationary, continuous noise sources. He concluded that roughly half of the bowheads react by moving away when the received level of continuous industrial noise is 110 dB in the 1/3-octave band of maximum signal-to-noise (S:N) ratio or when the S:N ratio in that band is at least 30 dB. This conclusion is somewhat subjective and deals with averages. Some individual bowheads react at considerably lower received levels (e.g., 20 dB S:N), whereas others do not seem to react unless levels considerably exceed 110 dB or 30 dB S:N.

A rapidly approaching boat is probably perceived by bowheads as a greater threat than is the continuous noise from a distant stationary site. Hence, reactions to approaching boats would be expected to begin at lower noise levels or S:N ratios. Boats have been identified as the industrial activities that cause the strongest and most consistent responses by bowheads (Richardson et al. 1985a,b). The thresholds of responsiveness estimated from the playback experiments and opportunistic observations of bowheads near stationary sites probably do not apply to rapidly approaching boats, although they may apply to the more consistent sounds from distant boats or from boats moving tangentially.

Miles et al. (1987) calculated the received levels of noise from the 13-m diesel-powered vessel Sequel as it approached bowhead whales during an experiment in 128 m of water. A mother and calf reacted when the vessel was over 3.4 km away. The received level at 4 km was 84 dB re 1 μPa in the most intense 1/3-octave band (400 Hz centre frequency) and the S:N ratio was 6 dB. These values are substantially lower than the aforementioned estimates of response thresholds based on continuous, stationary noise sources. Three experiments with the Sequel in shallow water provided similar results with bowheads reacting at estimated received levels of 92-99 dB in the most intense 1/3-octave band. Again these absolute levels are substantially lower than the 110 dB threshold estimated for stationary sources.

Recent studies in the eastern Alaskan Beaufort Sea found that fall migrating bowheads were more sensitive to a stationary offshore drilling operation than were the summering animals studied by Richardson (1985). No bowheads approached closer than 10 km to the drillship during continuous acoustic and aerial monitoring (Davis 1987; Evans et al. 1987). Median levels of noise received at hydrophones 10 km from the drillsite were 104 dB in the two most intense 1/3-octave bands (centred at 63, 80 Hz). The lowest and highest received levels over the 20 d period of continuous acoustic monitoring were 91 and 124 dB in the 1/3-octave band centred at 80 Hz (Greene 1987). The median levels were well below the 110 dB response level found in the Canadian Beaufort Sea.

Thus, the zone of responsiveness is variable and partly a function of noise source and whale activity. This range of variation will be considered in later analyses.

Zone of Masking

When there is an increase in the background noise level against which an animal is attempting to detect a sound signal, the signal-to-noise (S:N) ratio is reduced. If, for example, the signal of interest is a whale call, the background noise consists of natural ambient sounds plus any industrial or ship noise that may be present. If the receiving whale is close to an industrial source, the received industrial noise level will probably exceed the natural ambient level, and this will reduce the S:N ratio for the whale call. If the received whale call is intense, it will still be audible despite the reduced S:N ratio. However, if the whale call would be barely detectable in the absence of industrial noise, it may not be detectable in the presence of the noise. Such a call is said to be masked by the industrial noise (Terhune 1981).

The received level of a whale call is likely to be at least roughly related to the distance between the calling and the receiving whale. If the S:N ratio of a whale call received in the absence of industrial noise is low, the call was probably made by a distant whale. Thus, it is primarily the calls from distant whales that will be inaudible if the background noise level increases. Masking by elevated ship or industrial noise levels has the potential to reduce the distance to which a whale can hear calls from other whales, or from other sources of interest. This is the chief concern with regard to cow-calf pairs that are separated when the mother is off feeding. If noise from an approaching ship masks inter-animal calls before the cow and calf respond and rejoin each other, then at least temporary separation will continue and will be exacerbated if the cow and calf 'escape' in opposite directions.

It is emphasized that the actual importance of masking to whales, particularly baleen whales, is largely unknown. There is little information about the importance of long-distance communication to whales, or about the

significance of a temporary interruption in this ability. Long-distance communication must often be interrupted by the natural masking effects of the elevated noise levels associated with storms and moving ice. It is not known whether baleen whales can adapt to increased background noise levels by increasing the intensities or altering the frequencies of their calls; certain toothed whales apparently do this (Au 1980; Au et al. 1985). Source levels of bowhead calls are quite variable (Cummings and Holliday 1985, 1987; Clark et al. 1986), so it is possible that bowheads produce more intense calls when background noise levels are high.

Directional hearing has the potential to reduce the severity of masking when the signal (whale call) and dominant background noise are coming from different directions. It has been established that bowheads have directional hearing abilities, since they orient away from locations where airgun drillship or dredge noise is introduced into the water (Richardson et al. 1985b). If the calls of bowheads have any directional properties, this may provide some resistance to masking. These complications are discussed in more detail by Richardson et al. (1983).

Probability of Permanent Separation

In the following examples, we will use noise measurements from the Robert Lemeur underway at 10 knots to approximate noise from the MV Arctic. The Lemeur data of Greene (1987) and Miles et al. (1987) include analyses in 1/3-octave bands, whereas the earlier MV Arctic data do not. However, broadband levels from each ship are similar. We assume the whales are near the 'Belcher' site and transmission loss rates are as measured there in late summer by Miles et al. (1987). Estimated median ambient noise levels for that area are given by Miles et al. (1987).

Example 1: Absolute Received Level Criterion

The source level of the Robert Lemeur was 164 dB re 1 µPa in the 1/3-octave band centred at 100 Hz and median ambient noise in this band at the Belcher site was estimated to be 88 dB (Miles et al. 1987). At the Belcher site, 100 Hz noise does not diminish by 86 dB (i.e. from 164 dB to 88 dB)

until the receiver is more than 50 km from the source (Miles et al. 1987, p. 296-7). In this situation, the theoretical zone of audibility is >50 km in radius around the ship. Thus, the cow and calf can theoretically hear the ship while it is still >50 km away, assuming that they can hear a sound whose S:N ratio is 0 dB on a third-octave basis. In an earlier section (Zone of Responsiveness), it was noted that bowheads responded to approaching boats when received levels in the loudest 1/3-octave band ranged from 84-99 dB. In the present example, ambient noise will define the lower limit of response. Here we will assume that bowheads do not respond to a ship until received levels reach 99-100 dB. Under average conditions, the 99 dB level is reached in the 1/3-octave band at 100 Hz when the ship is 21 km away (Miles et al. 1987, p. 296). Therefore, whales would be expected to start to respond when the ship is 21 km away. At this time a cow and calf that are separated by 1 km would undoubtedly attempt to regroup.

The entire mother-calf bond has evolved to insure that nursing calves do not become permanently separated from their mothers. Thus, there is little doubt that the first 'escape' response to an approaching ship will for the calf and mother to re-establish physical contact. The key question in the above example is whether whale communications are masked when the ship is 21 km away. Can the cow and calf hear each other over the noise of the ship when they start to respond at 21 km distance? It is reasonable to assume that female bowheads would use their loudest calls in this situation. Source levels of 180 dB re 1 μPa at 1 m for bandwidths of $\leq$1/3 octave have been measured for bowhead calls (Clark and Johnson 1984; Cummings and Holliday 1985, 1987). Assuming the worst case of spherical spreading, transmission loss would be 60 dB in 1 km. Thus, at the 1 km separation distance assumed by our model, the calf would receive calls from its mother at 120 dB. These would be clearly audible over the median ambient noise of 88 dB plus the ship noise of 100 dB, which would total 100.3 dB. In fact, transmission loss rates measured at Belcher over 1 km are less than the spherical rate of 20 log Range; Miles et al. (1987) found a TL of 42.6 dB at 1 km range relative to the source level. Thus, the received level of the cow's call at the assumed calf's location would be about 137 dB, far above the ship noise level.

If we use the response threshold of 110 dB estimated for bowheads exposed to stationary noise sources on the summering grounds, then a more conservative model is evaluated. The 110 dB received level in the 100 Hz 1/3-octave band is reached when the ship is about 5.5 km away. At this distance whale communication would still not be masked since received levels of calls at the calf's location 1 km from the cow would be about 137 dB--comfortably above the background ship noise of 110 dB. It is reasonable to assume that the cow and calf would swim toward each other and that their net speed would be at least 10 km/h. Thus, it would take them six minutes to cover the 1 km separation distance. During this time the ship would have travelled 2.2 km (12 kts, 22 km/h) to a point 2.8 km from the whales (neglecting their motions). Inter-animal communication would be easily maintained in these circumstances since the received level of a 180 dB call would be 150 dB over a distance of 100 m and even higher at shorter distances. This is compared with ship noise of about 114 dB at 2.8 km, again based on TL data for 100 Hz sounds at the Belcher site (Miles et al. 1987, p. 296).

Example 2: Signal-to-Noise Threshold Criterion

In one instance, Richardson in Miles et al. (1987) found bowheads responding to an approaching boat at a S:N ratio of only 6 dB. Ship noise from the Lemeur would exceed median ambient levels by 6 dB in the 1/3-octave band centred at 100 Hz at distances of about 30-35 km from the whales. At these distances background noise is not elevated enough to have any effect on cow-calf communications over 1 km (or considerably greater) range.

Malme et al. (1987) concluded that about half of the bowheads responded when the signal-to-noise ratio of noise from a stationary industrial site reached about 30 dB. This S:N ratio would be reached at Belcher when the ship was only 1.9 km from the whales. At this distance, ship noise would be about 118 dB. This is still comfortably less than the received levels (137 dB) of the louder bowhead calls at 1 km. Given that it takes about six minutes for the cow and calf to rejoin and given that the ship will travel over 2 km in that time, it is conceivable that the ship could pass between the cow and calf. This would undoubtedly cause a temporary disruption in communications. This disruption would only occur in situations where the ship track passed

between the cow and calf, and in the unlikely event that the whales waited for the S:N ratio to reach 30 dB before reacting. Available data suggest that this threshold for stationary noise sources does not apply to moving sources such as ships.

Conclusions

The evidence modelled above indicates that bowhead cow-calf pairs are very unlikely to become separated by noise and/or disturbance from approaching tankers or other ship traffic. This result is not surprising when the strength of the mother-calf bond is considered. Their behavior patterns have evolved to insure that they do not become separated even during the extremely noisy conditions that occur during storms and high winds.

In the unlikely event that temporary separation did occur, the consequences would probably not be serious. Observations summarized in Section 8 of this report indicate that whales may move about 6 km to the side of the ship track. Thus, a cow and calf that swim in opposite directions might end up 12 km apart after the ship has passed. At this distance, typical transmission loss in the Belcher area is about 60.4 dB (relative to the 1 m source level) at 100 Hz. Thus, received levels of loud bowhead calls at 12 km range would be about 120 dB, which is well above median ambient level of 88 dB. Thus, the cow-calf pair should have no difficulty re-establishing contact with one other after the ship has passed. Overall, the concern about the potential for permanent separation of cow-calf pairs does not seem to be justified based on the available evidence.

10. INTERFERENCE WITH BOWHEAD HARVESTS

The Concern

The Beaufort Environmental Monitoring Project workshop in March 1987 raised the concern that tanker traffic along the Alaskan coast of the Beaufort Sea would interfere with the harvest of bowheads during their fall migration. The concern centered on the hunts carried on by Inupiat whalers from the communities of Kaktovik and Nuiqsut (see Figure 1 for locations). The workshop believed that bowhead distribution patterns might be altered by tanker traffic causing fewer bowheads to occur in nearshore waters where they are accessible to the whalers who use small boats. Such a distribution change could reduce the kill of whales to the detriment of the Inupiat communities that rely on the bowhead hunt.

This concern is analyzed in the following paragraphs by documenting the present distribution of bowheads off Alaska and the distribution of bowhead kills. The known responses of bowheads to ship traffic will then be applied to these distributions to predict possible effects and to determine whether distribution changes could be detected and attributed to tankers.

Present Distribution of Bowheads

The late summer (August) and fall distribution of bowheads in the Alaskan Beaufort Sea has been studied annually since 1979 by D.K. Ljungblad and co-workers from the Naval Oceans Systems Center for U.S. Minerals Management Service. Sightings in the eight-year period, 1979-86, are plotted in Figure 47. There has been a total of 1064 sightings of 1870 individual whales during this period. The data in Figure 47 are not corrected for differential survey effort, but they do give an overview of the general distribution patterns. The apparent decreases in density offshore are probably largely a reflection of lower survey effort in these offshore waters. In waters west of Barter Island (= Kaktovik), the nearshore limit of migrating whales is approximately the 18-20 m depth contour.

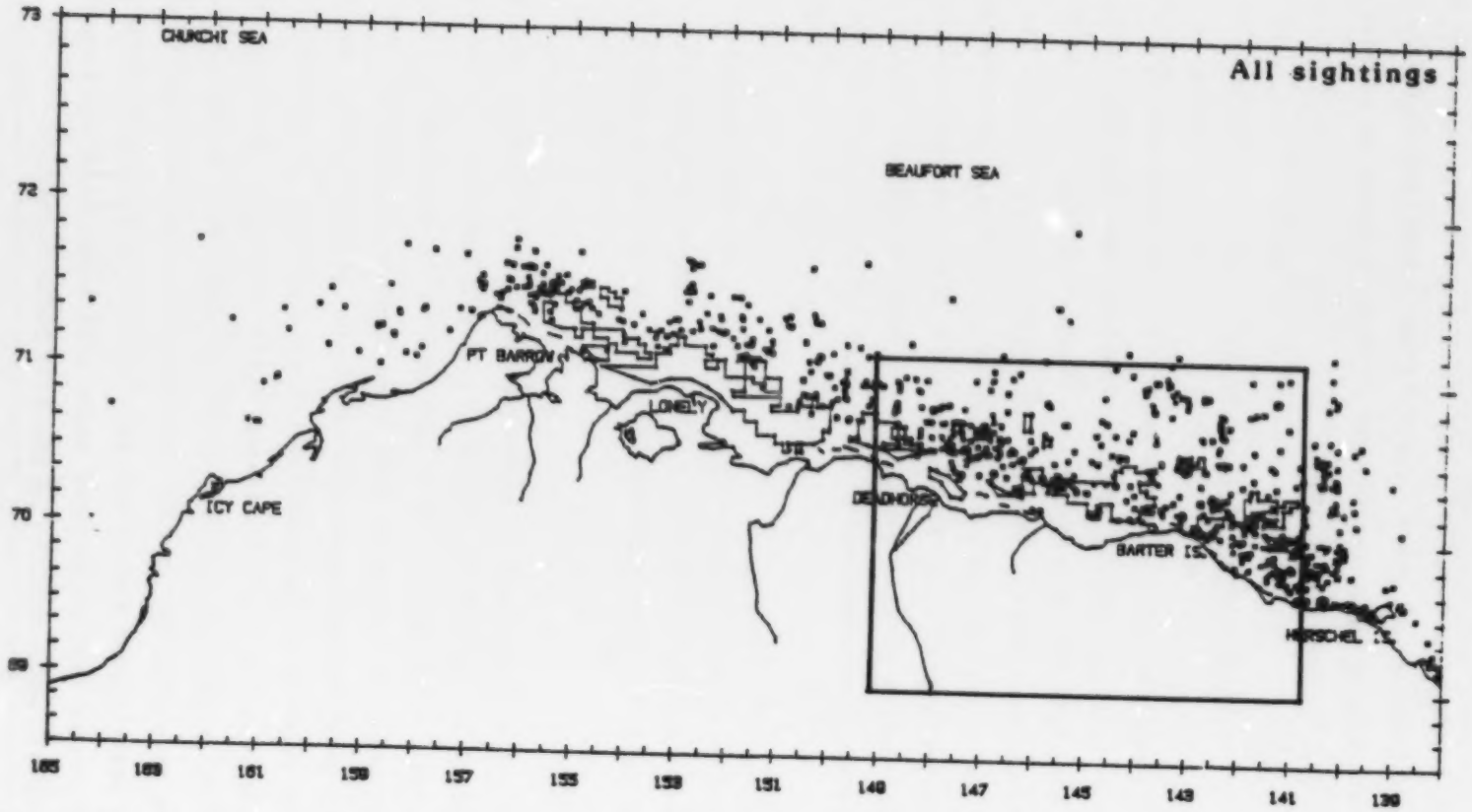


Figure 47. Summary of all fall sightings of bowheads in the 1979-1986 period during aerial surveys by D.K. Ljungblad and co-workers for U.S. Minerals Management Service. The large square is the area covered by the bowhead kill map in Figure 48. Smaller outlined areas depict OCS oil and gas lease sale tracts in Alaska. (Source: Ljungblad et al 1987).

The available data suggest that tankers moving west from Amauligak will traverse the late summer feeding area and fall migration routes of the bowhead. Within about 100 km of shore, there is no compelling evidence to suggest that one route should be preferred over another in terms of numbers of bowheads influenced by the tanker traffic.

Distribution of Whale Kills

As part of a communications program undertaken in conjunction with offshore exploratory drilling in the Alaskan Beaufort Sea in 1986, a joint working group of oil industry personnel and Inupiat whaling captains from Kaktovik and Nuiqsut was formed. One of the tasks of this group was to document the areas where whaling has occurred in the modern era. This was done by interviewing whaling captains to determine where kills by living captains have been made. The results of this exercise have been plotted in Figure 48, which shows the approximate locations of 40 bowhead kills, as reported by the whalers.

It is clear from Figure 48 that the main hunt is restricted to the coastal and nearshore waters off Kaktovik. This is not surprising since the hunt is conducted from outboard powered small boats in often ice-infested waters.

The success of the fall hunt is quite variable. Local quotas (recently Kaktovik-3, Nuiqsut-1) are filled in some years (e.g., 1986) but no whales at all are taken in other years (e.g., 1985). The lack of kills is not a function of differential interest in the hunt from year-to-year. If weather and ice conditions permit, then whalers undertake the hunt. In some years, however, bad weather and ice conditions can greatly reduce the number of whaleboat days at sea. This, in turn, leads to reduced kills. In other years, weather conditions can be relatively benign, but no whales are taken because bowheads do not occur close to shore. The factors that determine the variation in whale distribution from year-to-year remain unknown. These natural annual variations in the numbers of whales that occur near shore will complicate any program to monitor the effects of tanker traffic on the fall bowhead hunt.

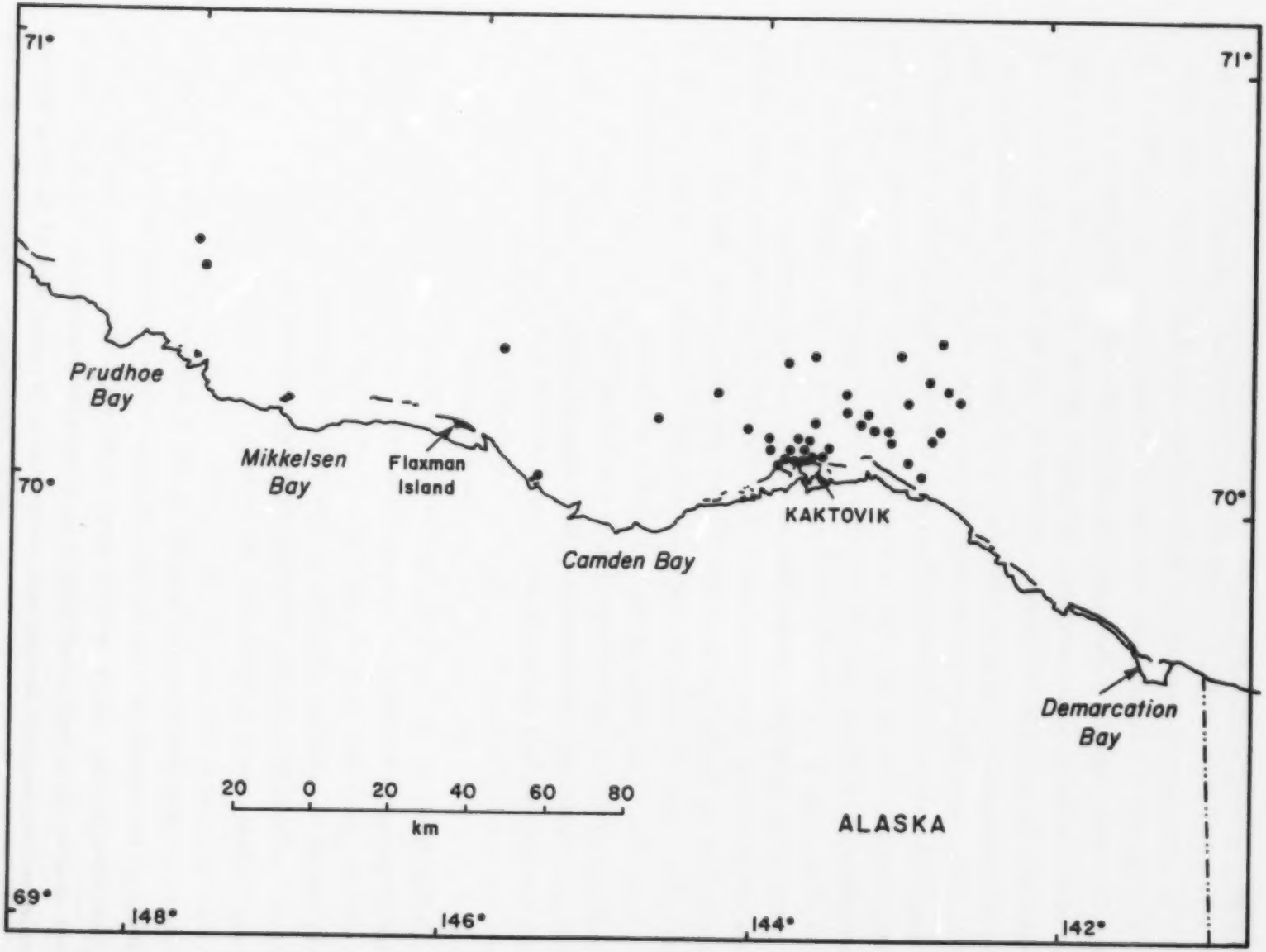


Figure 48. Locations of bowhead kills as mapped by Inupiat whaling captains from Kaktovik and Nuiqsut in 1986 (Source: Oil/Whalers Working Group, 1986).

Whale Responses to Tanker Traffic

The responses of bowheads to ship traffic have been reviewed in previous sections (8 and 9). It is clear that whales in the path of the ship will move out of its way. Animals a few km to the side of the track will also move away. There are few data on the distances at which whales to the side of the ship track react to approach of the ship. In one case in September 1986, whales 1-3 km from the track of a supply ship moved away, whereas an animal 6 km did not move. Several other incidents also suggest that about 6 km is often the distance that bowheads move to the side of an approaching ship. Thus, as a worst case we can assume that all bowheads will move 6 km from the track creating a 12 km wide track that is temporarily free of whales.

Migrating bowheads approaching an offshore drilling operation during the open water season diverted around the operation. Virtually no whales passed closer than 10 km from the drillship and few were closer than 15 km (Davis 1987). This created a 20+ km wide zone that was not used by the whales. Thus, it seems clear that ship traffic and offshore industrial activity can and do cause changes in bowhead distribution patterns. This raises two important questions. Will the ship travel close enough to shore to affect the coastal whales hunted by the whalers and if these nearshore whales are affected, how will they react?

The track of the shuttle tanker from Amauligak will be quite variable depending on the location of the pack ice. The ship will try to avoid heavy, multi-year ice. For much of the time ice will not be a problem and the ship will travel far enough offshore of Kaktovik and Nuiqsut to avoid having any effects on huntable whales. However, there will undoubtedly be many instances where routes closer to shore will be used.

It is not possible to be precise about how close to shore the tanker needs to be to affect the whales. The available evidence suggests that at least some of the whales within about 6 km of a ship will be affected, but that migrating animals might avoid a disturbance source by 10-15 km. To be conservative, we will assume that if the ship is more than 15 km from whales, then there will be no effects on whale distribution. Bowhead kills have

occurred up to about 20-23 km from shore NE of Kaktovik (Fig. 48). Thus, it can safely be assumed that a ship over 38 km (15 + 23 km) from shore will not affect the bowhead hunt.

In those cases when the ship is closer than 38 km from shore, the question is, 'How do the whales respond?' Are whales on the south side of the ship track displaced even closer to shore or do they avoid entering shallow water? There is little direct evidence on this question. In the fall of 1986, migrating whales avoided a drilling operation at the Hammerhead side, which was 20 km offshore between Kaktovik and Prudhoe Bay. In this situation whales did not occur closer than 10 km from site, but they passed both south and north of it. Thus, bowheads moved to within 10 km of shore to pass south of the operation (Davis 1987). Assuming that this finding can be applied to ship traffic, then passing ships could be as close as 20 km from shore without causing nearshore whales to move offshore. In fact, it is quite likely that the ship would cause some whales to move closer to shore and to the Inupiat whalers.

It is not known with certainty how migrating whales would react to vessel traffic even closer to shore, but there are indications that bowheads tended to move offshore when subjected to other types of industrial noise in summer (Richardson et al. 1985b). Presumably, if a ship passed very close to shore, the whales would all move to the offshore side of the ship track. It is not known what the critical distance to shore might be. However, it seems unlikely that relatively large shuttle tankers would often travel this close to the coast.

Conclusions

On most passages, the shuttle tanker would not pass within 40 km of shore off Kaktovik and therefore no huntable whales would be affected. On those passages when the tanker passes between 20 and 40 km from shore, it is likely that some bowheads will be displaced southward closer to the whalers. It seems unlikely that the tanker would travel close enough to shore to force even the nearshore whales to 'escape' to the offshore. The distance from shore at which this behavior would be triggered is not known.

Detection of Effects

The BEMP workshop wondered whether the subtle changes in distribution patterns that might affect hunting success would be detectable with standard whale monitoring techniques. The simple answer to this question is that it probably will not be possible to monitor the effects of this shipping on the bowhead hunt. The main problems relate to natural variability and an inability to use certain study techniques.

The best way of documenting effects on whale distribution, and hence hunting success, is to use aerial behavioral observation techniques to directly document the responses of nearshore bowheads to the passing tanker. As discussed earlier these observations must be made in real-time as the tanker passes. Observations after the fact will be confounded by normal movement patterns (see Section 5) that will quickly mask responses to the tankers. It is quite likely, however, that direct aerial observation programs will not be permitted by the Alaska Eskimo Whaling Commission (AEWC) in or near any active whaling operation. Thus, the best that could be done would be to document effects on distribution in non-hunting areas or in the absence of hunters and apply these results to the Kaktovik and Nuiqsut hunting areas.

Indirect methods of evaluating hunting success before and after the onset of tanker traffic seem unlikely to provide much useful information. There are no historical data on numbers of whaleboat days, numbers of sightings, etc.; these types of data would be necessary to quantify annual catch-per-unit-effort (CPUE). Also it is quite likely that hunting effort may increase after the International Whaling Commission's recent decision in 1988 to allow increased bowhead quotas. New technology for the harpoon guns and more effective use of radio transmitters on harpoon floats may increase hunting efficiency. These changes combined with the large natural variations in ice and weather conditions and in the timing and routing of bowhead fall migration will tend to mask any real trends in hunting success related to the onset of tanker traffic.

It seems unlikely that indirect monitoring methods will be useful except possibly over very long periods. Direct monitoring would be effective, but probably will not be allowed since the AEWC and other groups are likely to be concerned that the monitoring itself might affect the hunt.

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APPENDIX 1.

Numbers of bowhead whale calves, small subadults, large subadults and adults measured during each year (Table 22), during each half month period (Table 23), and in each geographic subdivision (Table 24).

Table 22. Numbers of bowhead whale calves, small subadults, large subadults and adults measured during each year, 1981-1986.

Year	Calves	Small Subadults	Large Subadults	Adults	Total
1981	1	4	12	57	74
1982	43	60	141	122	366
1983	0	8	12	3	23
1984	5	153	170	73	401
1985	11	374	313	108	806
1986	26	111	113	68	318
Total	86	710	761	431	1988

Table 23. Number of bowhead whale calves, small subadults, large subadults and adults measured during each half month period, 1981-1986.

Period	Calves	Small Subadults	Large Subadults	Adults	Total
16-31 Jul	0	0	2	3	5
1-15 Aug	2	37	34	58	131
16-31 Aug	36	417	414	196	1063
1-15 Sep	25	214	228	112	579
16-30 Sep	18	39	72	50	179
1-15 Oct	5	3	11	12	31
Total	86	710	761	431	1988

Table 24. Number of bowhead whale calves, small subadults, large subadults and adults measured in each geographic subidivison, 1981-1986.

Area	Calves	Small Subadults	Large Subadults	Adults	Total
Central Alaska	1	3	4	5	13
Offshore C Alaska	0	0	0	0	0
EC Alaska	6	1	7	14	28
Offshore EC Alaska	0	0	0	0	0
Eastern Alaska	7	19	19	19	64
Offshore E Alaska	0	0	0	0	0
Komakuk	15	133	130	40	318
Herschel Island	32	97	178	100	407
King Point	7	339	220	9	575
Offshore Yukon	1	2	2	4	9
Interface	1	57	52	5	115
Industrial	0	3	12	18	33
Delta Shelfbreak	7	0	13	23	43
Offshore Delta	0	0	1	4	5
Tuk. Pen. Shelf	5	25	37	25	92
Offshore Tuk. Pen.	1	0	2	5	8
Offshore Bathurst Pen.	0	1	10	10	21
Franklin Bay	2	21	50	85	158
Cape Parry	0	4	9	20	33
NW Amundsen	0	0	2	3	5
NC Amundsen	1	5	13	41	60
SC Amundsen	0	0	0	0	0
NE Amundsen	0	0	0	1	1
	0	0	0	0	0
Total	86	710	761	431	1988

APPENDIX 2.

New inter-day resightings of bowheads

Table 25. Inter-day resightings of bowheads resulting from recent inter-study comparisons.

Source of Photos	First Photographed				Resighting				Time Between Sightings (days)	Whale No.
	Date	Loc'n[a]	Latitude	Longitude	Date	Loc'n	Latitude	Longitude		
1985										
CRC-CRC	19 Aug	HI	69°30'N	137°40'W	20 Aug	I	69°23'N	137°14'W	1	7476
CRC-LGL	25 Aug	KP	69°04'N	137°47'W	27 Aug	KP	69°06'N	137°51'W	2	6453
CRC-LGL	25 Aug	KP	69°04'N	137°46'W	6 Sep	KP	69°06'N	137°34'W	12	5760
CRC-(LGL-LGL)	25 Aug	KP	69°05'N	137°47'W	27 Aug	KP	69°06'N	137°46'W	2	5694
					6 Sep	KP	69°09'N	137°26'W	10	"
CRC-(LGL-LGL-LGL)	25 Aug	KP	69°10'N	138°06'W	27 Aug	KP	69°06'N	137°49'W	2	5589
					30 Aug	KP	69°18'N	138°17'W	7	"
					6 Sep	KP	69°13'N	137°19'W		"
CRC-(LGL-LGL)	25 Aug	KP	69°09'N	138°02'W	13 Sep	KP	69°26'N	138°36'W		6005
					14 Sep	KP	69°06'N	137°53'W		
1986										
CRC-LGL	26 Aug	I	69°24'N	137°13'W	15 Sep	K	69°39'N	140°29'W		5933[b]

[a] HI = Herschel Island, KP = King Point, I = Interface, K = Komakuk, see Figure __ for locations of study blocks.
[b] This bowhead was also photographed on 8 September 1985 at 69°37'N, 140°13'W (Richardson et al. (1987b, p. 237).